Arthur D Little

Aggressive Growth in the Use of Bioderived Energy and Products in the United States by 2010

Final Report

October 2001
U.S. Department of Energy

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Reference: 71038

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Part 1

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The objective of this study was to identify ways to increase significantly the consumption of bioderived energy, fuels and products by 2010.

- The objectives were based in part on:
  - The Biomass Research and Development Act of 2000 (Public Law 106-224)
  - The National Sustainable Fuels and Chemicals Act of 1999
  - Former President Clinton's Executive Order 13134 "Developing and Promoting Biobased Products and Bioenergy"
- The objectives are also supported by the Bush Administration's National Energy Policy[1]
  - Increased production and utilization of biomass will likely utilize environmentally friendly technology that will increase energy supplies and help raise the living standards of the American people, particularly in rural and semi-rural areas
- This report covers a broad range of biomass energy and products, based on open literature data
  - Biopower and bio-heat (e.g. wood-fired power plants, co-firing of biomass with coal or natural gas)
  - Biofuels (e.g. bioethanol, biodiesel, bio-FT-diesel[2])
  - Bioproducts (primarily carbohydrate and lipid based chemicals) both for existing and new products and applications
- Two scenarios were developed to illustrate the potential for and impact of increased biomass use for energy and products:
  - A Business As Usual scenario represented what could happen if no special additional supports are implemented
  - An Aggressive Growth scenario aimed at achieving more than doubling[3] by 2010 or soon thereafter
- The study's scope specifically excluded several categories of products conventionally made from biomass:
  - Paper, lumber and other conventional wood products
  - Food, food ingredients and food by-products
  - Pharmaceuticals and "nutraceuticals"
  - Textiles

1. "National Energy Policy: Reliable, Affordable, and Environmentally Sound Energy for America's Future", Report of the National Energy Policy Development Group, May 2001
2. FT-diesel is diesel fuel made via Fischer-Tropsch synthesis.
3. A tripling benchmark was used in this study

Arthur D. Little and USDOE identified the underlying policy objectives for the aggressive targets for increases in biomass use.

Broad Study Objective	More than double the use of biomass-derived materials in the U.S. by 2010

To Address the Underlying Objectives...	…the policies options should:
Reduce environmental burden of producing and utilizing energy and products	• Be focused on the environmental end-result, not the path to get there • Address all relevant environmental concerns
Stimulate rural economic development	• Focus on developing competitive economic activity in rural areas, preferably value-added activity
Improve U.S. balance of payments position	• Focus on U.S.-generated biomass (e.g. options should not support import of Indonesian rubber or Brazilian ethanol)
Improve United States energy security	• Focus on pathways that directly offset fossil fuel (e.g., not food & feed or pulp & paper)
Accelerate development of competitive U.S. technology	• Focus on technologies with competitive potential for U.S. industry, not necessarily on ones that are closest to large-scale application • Eliminate barriers for technology development

With sufficient investment and government support, significant increases in the use of biomass energy and products in the U.S. by 2010 are feasible...

- Sufficient biomass is expected to be available in the United States to more than double its use but prices at high volume are expected to exceed $20/dry ton farm-gate (~$1.1/GJ; $1.2/million BTU)
- Several significant implementation options appear nearly ready for implementation, though they will require a supportive regulatory and tax environment to achieve rapid and substantial market penetration:
  - Biogas-to-power (primarily landfill gas) and biomass co-firing with coal provide relatively attractive ways to considerably increase biopower capacity
  - Increased use of bioethanol as a gasoline oxygenate; it alone represents a potential significant increase in use from today's biofuel consumption (provided the current tax credit is continued and the oxygenate requirement in RFG remains)
  - Fermentation-based monomers, pyrolysis-derived phenolics and lipid-based products offer near-term opportunities for increasing bioproduct use
- These options could provide significant environmental and rural economic benefits by 2010 with aggressive deployment:
  - Over 95 million ton per year reduction in carbon dioxide reduction emissions
  - Significant criteria pollutant emission reductions (390 thousand tons SOx avoided; 440 thousand tons NOx avoided)
  - Over three billion dollars per year added economic activity in rural areas by 2010 from feedstock production alone (primary impact with aggressive implementation)
- When looking out to 2020, additional long-term options now under development may significantly expand that impact and could help double biomass-based energy and product use by 2015:
  - Biogas-to-power (e.g. including landfill, sewage, and digester gases) and gasification based biopower (e.g. BIGCC for onsite power)
  - Ethanol for gasoline blending obtained with advanced cellulosic-based technology
  - Advanced gasification for fuels production for Fischer-Tropsch (FT) diesel
  - Bio-polymers via fermentation based processes
  - Lipid-based feedstocks for polyurethane foam and coatings applications as an example

... though doubling of use is not likely to happen before 2015.

1. Energy and fuel prices were compared with the 2010 reference case of the USDOE EIA 2001 Energy Outlook, $21.4/B oil price.

Together the most attractive options can significantly increase biomass use in an aggressive growth scenario.

Application Category	Growth Potential: Business as Usual (BAU)	Growth Potential: Aggressive Growth	Support Requirements
Biopower	• 40% increase in capacity from baseline of 10,000 MW to 14,000 MW in 2010 • Baseline does not grow and stays at 10,000 MW in 2010	• Capacity increases by 100% in 2010 (additional 13,000 MW from baseline of 10,000 MW) • Biopower plants based on advanced BIGCC important in post 2010 timeframe	• Modest support, expected to produce power at competitive cost[1]
Biofuels	Gasoline additives (e.g. as oxygenates for MTBE replacement) – 50% increase by 2010, ~800 million additional gallons of ethanol over baseline of 1500 million gallons ethanol consumed in 2010 – Baseline growth results in 200 million gallon ethanol	• Gasoline additives –100% increase by 2010, additional 2300 million gallons over baseline of 1600 million gallons ethanol in 2010 • FT-diesel from gasification in post 2010 period (leverage biopower development) • Baseline grows 300 million gal. ethanol	• Continuation of oxygenates requirement in reformulated gasoline • Continuation of current bioethanol fuel tax credit or similar direct support (e.g. renewable content standard) • Extension of tax credit to all bio-derived fuels • Renewable fuel content requirement • Advanced ethanol technology may eventually reduce need for tax credit
Bioproducts	• Additional 600 million pounds product in 2010 over baseline of 21 billion pounds products (3% increase) • Baseline grows 3400 million pounds bioproducts	• 7.5 billion pounds product additional in 2010 over 21 billion pound baseline (35% increase) • Baseline grows 3400 million pounds • Broad implementation of fermentation-based processes, primarily for polymers	• Aggressive government support in technology development and demonstration • In long-term, expect cost competitiveness with petroleum analogs

1. Energy prices were based on U.S. EIA's 2001 Annual Energy Outlook, 2010 reference case of $21.4/barrel oil in 1999 dollars. The cost of energy sources was taken from the industrial sector, transportation sector, and electricity generators for 2010, reference case.

The implementation of the attractive options can lead to significant environmental benefits, particularly CO_2 abatement.

Category	Environmental Benefits in 2010	
	Business as Usual (BAU)	Aggressive Growth
Greenhouse Gas Emissions	• 26 million metric tons per year CO_2 avoided and 24 thousand metric tons per year CH_4 avoided in 2010 for biopower • 5 million metric tons per year CO_2 avoided in 2010 from biofuels • 0.1 million metric tons per year CO_2 avoided in 2010 from bioproducts	• 80 million metric tons per year CO_2 avoided and 87 thousand metric tons per year CH_4 avoided in 2010 from biopower • 14 million metric tons per year CO_2 avoided in 2010 from biofuels • 1.3 million metric tons per year CO_2 avoided in 2010 from bioproducts
Criteria Air Pollutant Emissions	• 130 thousand metric tons per year NO_x and 130 thousand metric tons per year SO_x avoided in 2010 from biopower	• 440 thousand metric tons per year NO_x and 390 thousand metric tons per year SO_x avoided in 2010 from biopower
	• Improvements in criteria pollutant emissions are not a driving factor in biofuel and bioproduct options	
Water and Soil Quality	Biomass production could have some positive impacts on the water and soil quality in the US, although very careful management and attention will be necessary to prevent degradation.	

Achieving significant impact will require the application of new biomass technologies to new applications...

- Existing biomass utilization is based on mature technology and occurs mostly in mature markets (e.g. pulp & paper, starch manufacture)
- Combinations of new technologies and new applications are required to achieve rapid and significant growth in the use of bioderived energy and products
- Key improvements in technology for targeted markets could aid the implementation of biomass-derived energy and products:
  - Development of lower cost, high-quality biomass feedstocks (e.g. energy crops, “harvesting” of agricultural residues) and the establishment of large-scale distribution infrastructure to make these biomass feedstocks available in high volume
  - Development and demonstration of low-cost biomass conversion processes, which could result in broader cost-competitiveness for biomass-derived power, fuels, and products in the long term (post 2010)
  - Demonstration of the viability and reliability of technologies currently under development
  - Development of new product applications with enhanced performance
  - Development of optimal information systems to minimize the impact of industry inertia on the market penetration rate of biomass technologies and their products
- Integrated production of energy and products in “Bio-refineries” could contribute to improving the cost competitiveness of biomass options with fossil-based counterparts; this will likely require new inter- and intra industry collaborations

... but rapid near-term growth will also require expansion of existing uses.

To achieve these benefits, significant cost barriers must be overcome which will require significant and focused government support.

- Given current projections for crude oil and utility prices[1], some of the long-term[2] options are expected to require considerable one time investments by stakeholders and some will require sustained support
- Developments in crude oil price are likely to have considerable impact on all options, particularly on the fuels & products options that are competing directly with petroleum-analogs and will shift the competitiveness of the options versus petroleum fueled alternatives
- Projected feedstocks of >$20/dry ton farm-gate pose a challenge with oil prices projected for 2010 by EIA
- High feedstock and capital recovery costs are the main barriers to significant increases in the use of biomass-derived energy and products in the U.S.:
  - Most current technologies are not cost-competitive with fossil-derived fuels, power, and products in new markets without government support
  - Considerable research, development and demonstration funding will be required to prepare the technologies for commercial application
  - Significant one-time cumulative investments (tens of billions of dollars) will be required for plant construction and infrastructure development (Not accounting for investment that otherwise may be made)
  - Even then many of the options will carry higher operational costs than conventional alternatives
- To overcome these barriers, two types of support are critical:
  - Sustained support for crop (resource) production, biomass conversion, and product use through tax credits, farm supports, and subsidies will be required if use of biomass-derived energy and products is to be dramatically increased
  - Strong support for R&D/D focused on long-term improvements in technology that will eventually make the technology cost-competitive with conventional fuels and power sources
  - Coordination and careful planning of such support will be critical to its success
- The USDOE, USEPA and USDA could play a key coordinating role with interested industries if such an effort were undertaken

1. The EIA 2001 Annual Energy Outlook reference case has a $21.4/B oil price in 2010 (in 1999 dollars). The 2010 prices are: Industrial sector: electricity $11.2/million BTU; natural gas $3.3/million BTU; Electric generator sector: natural gas $3.0/million BTU and steam coal $1.0/million BTU; Transportation sector: motor gasoline $10.9/million BTU and distillate fuel $8.9/million BTU (excluding taxes).
2. In this context, near-term means having significant impact before 2010, while long-term means significant impact in the 2010-2020 timeframe.

The scope for this report was defined jointly by DOE and ADL...

Task I: Biomass Resource Assessment
- Review literature (an independent assessment was out of scope)
- Segment biomass by geography, source, type and availability
- Identify price/volume relationships
- Identify gaps in available literature

Task II: Identify Routes for Significant Increases in Biomass Utilization
- Review current projects and programs
- Develop list of potential biomass products and technologies
- Identify technical, economic, infrastructure and market barriers to the implementation of biomass supply chains
- Identify the most attractive biomass supply chains

Task IV: Benefits and Impact Analysis
- Modify existing fuel chain tools to apply to U.S. and a range of products
- Quantify the emissions and economic impact of alternative supply chains
- Quantify relative attractiveness of competing chains
- A life cycle analysis of costs and/or emissions was not part of the scope of this study

Task III: Market / Scenario Analysis
- Use ADL "visioning" tools to identify the tasks which must be taken to achieve DOE goals
  - Aggressive increases in biomass use by 2010 (more than double)
  - "Business as Usual" scenario
- Identify barriers to achieving this level of increase
- Develop a strategy for the United States Government moving forward, taking advantage of all knowledge gained in preceding tasks and synergies among alternative chains

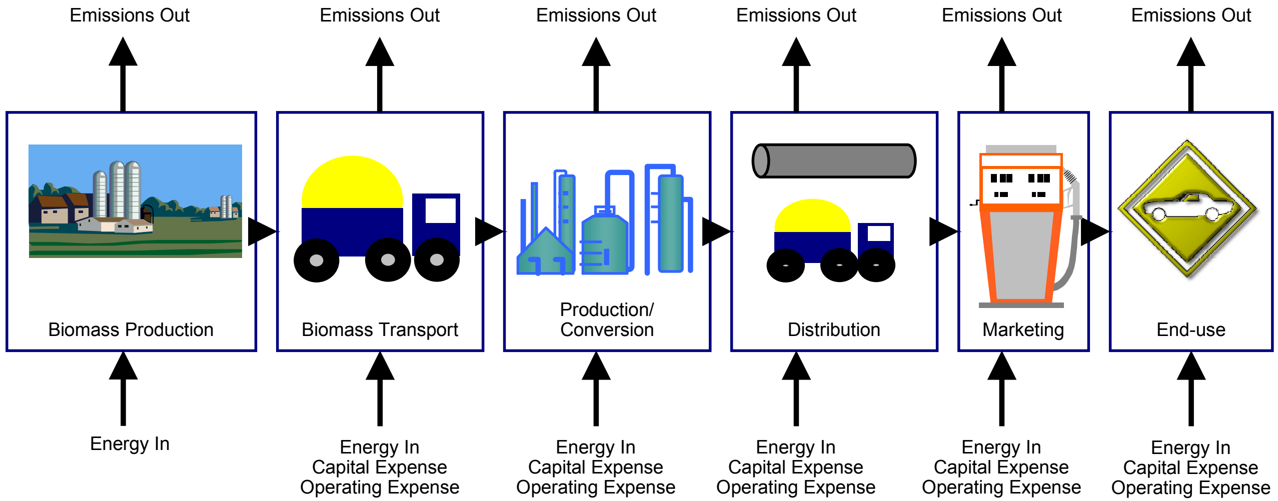
... USDOE and USDA staff were given opportunities to provide input to and comments on the analysis.

The report focuses on near-term[1], high-impact solutions.

- The near-term (primarily until 2010) nature of the scope forced us to focus on technologies that are close to commercialization, though some less mature technologies could have higher impacts
- The high-impact aspect of the scope focused our analysis on options that are broadly applicable at high market volume, though some other options may be attractive in the near-term:
  - While in a long-term, high-impact scenario negative feedstock values are unlikely to be sustainable, in the short term they can materially impact the economics of early plants (e.g. Masada MSW to ethanol project)
  - Use of idled capacity plants (paper mills, biopower plants, etc.) could provide significant capital cost advantages for some early plants (especially in California)
- The cost impact of environmental degradation was not internalized in the economic analysis in this project:
  - Environmental degradation can have significant economic impact in the long term
  - Similar to most economic analyses, this study considered these factors as externalities (i.e. they are not included in the economic evaluation) as they are difficult to quantify
  - Some researchers internalize these factors into the economic evaluation, which negatively affects the economics of less environmentally friendly technologies
- Secondary or tertiary impacts on energy use and environmental impact were not considered, as would be done in a life cycle analysis

1. In this context, near-term means having significant impact before 2010, while long-term means with potentially significant impact in the 2010-2020 timeframe.

Throughout the report, each potential fuel/power/product was analyzed on a "value chain" basis: from plantation/collection site to the market of use.



Biopower, all pieces, including energy losses of transmission and distribution (but not investment costs of transmission and distribution)

Biofuels, "well to wheel" analysis, not including vehicle retrofit costs

Bioproducts, up to primary processing plant-gate

Value Chain Analysis:
- Considers all steps involved in production and use of biomass energy, fuels and products
- Incorporates multiplicative effects in value chain
- Allows for detailed analysis of each module and consideration of a range of combinations
- Considers all energy inputs into the value chain, including secondary not tertiary inputs; i.e. energy used to produce diesel for trucks is included but energy use to make the trucks or the refinery is not included

A life cycle analysis was not part of the scope of this study.

The baselines were defined on a output basis (biomass ending up in product) to ensure that efficient process technology is emphasized.

References	• **Biopower** – **Pulp & Paper Industry Steam Production:** Estimated that 100% of electricity production from wood & wood wastes is in the pulp & paper industry and is converted into electric power at 20% efficiency, with 80% of the waste heat recovered. Difference between actual use of hog, bark and spent liquor solids as internal fuels and implied need at 20% generation efficiency is assumed to be converted directly into heat and used onsite. (Data from Manufacturing Consumption of Energy Survey, EIA) – **Electricity Production from Wood & Wood Wastes; Electricity Production from MSW; Electricity Production from Other Biomass Wastes** from the EIA Renewable Energy Annual 1999 • **Biofuels** – For ethanol: Energy Information Administration (EIA) website: http://www.eia.doe.gov/cneaf/solar.renewables/alt_trans_fuel98/table10.html –Data for 1999: – 890,200,000 GGE[1] ethanol as a fuel oxygenate, – 2,489,000 GGE E85 (2,116,000 GGE ethanol) – 59,000 GGE E95 (56,000 GGE ethanol) • **Bioproducts:** Ahmed & Morris, The Carbohydrate Economy, 1992
Methodology	• The biomass baseline was defined on an output basis. The biomass mass equivalent was estimated with 17.5 GJ/ton biomass energy density for fuels and electricity. Industrial products were estimated to have an energy density of 80% of raw biomass (0.8 X 17.5 GJ/ton = 14 GJ/ton). The actual biomass used to make the products is greater than the amount shown because of process inefficiencies. • The economic value of the categories was estimated with EIA 2001 Energy Outlook 2010 reference case prices of $4.4/million BTU for primary energy (used to value steam); $11.2/million BTU for industrial sector electricity; and $10.9/million BTU for transportation sector motor gasoline. Products were assigned a value of $0.30/lb.

1. GGE: gallons gasoline-equivalent. Converted into gallons of ethanol at 129 MJ/gallon gasoline, 91 MJ/gallon ethanol (HHV)

Current annual use of bioenergy & bioproducts amounts to 108 million tons of biomass (output), ~2 Quads of energy, or $14 billion in product value[1].

- Biomass is a small part of the current United States primary energy mix (3.2% of primary energy use)
- In the United States, 75% of non-hydro renewable power generation is biomass-based, accounting for 1.5% of total power generation
- Biomass fuels (mostly ethanol) represent less than 1% of total transportation fuel consumption (and 20% of alternative fuel use including MTBE and CNG)
- For nonpower and fuel applications, industry is by far, the largest consumer of biomass (in the form of wood)
  - Applications are dominated by wood and starch for paper products, although a portion is used for selected materials and chemicals

Category	Baseline Annual Production: Output Basis			
	Conventional Units	Mass-basis (tons)	Energy-basis (TJ, 10^{12} J)	Economic-basis ($million value)
Biopower				
Pulp & paper industry steam production	1.4 billion MMBTU	82 million	1,440,000	$6000
Electricity production from wood & wood wastes	33 billion kWh	6.8 million	120,000	$1300
Electricity production from MSW	19 billion kWh	3.9 million	69,000	$730
Electricity production from other biomass wastes	3.4 billion kWh	690,000	12,000	$130
Biofuels				
Ethanol	1.3 billion gallons	6.4 million	113,000	$1,200
Bioproducts				
Industrial products	8.7 million tons	8.7 million	121,000	$5,200
Total		**108 million**	**1.9 million**	**$14,600**

1. Detailed assumptions are in the “Baseline Use of Biomass” section of this report.

Sufficient biomass is available to more than double biomass use but farm-gate prices at high volume are expected to exceed $20/dry ton[1].

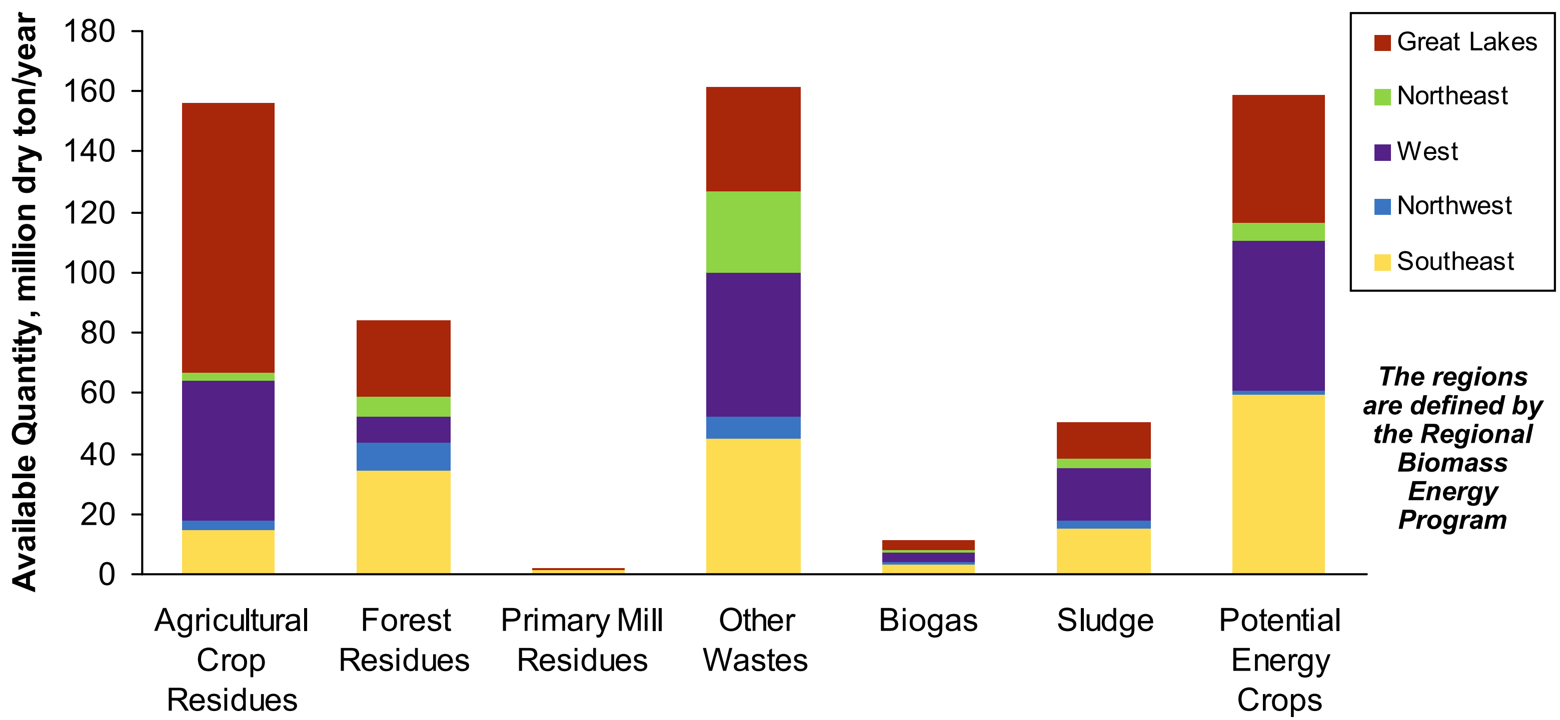
- Available literature data indicates that over 600 million dry tons of biomass are available within the U.S. at farm-gate prices between 0 and 40 $/dry ton (0 to ~$2.3/GJ or $2.4/million BTU):
  - Available biomass is defined as a resource that is currently or potentially collectable and not currently used as energy, fuel or any beneficial use and is potentially usable (not contaminated or comingled)
  - Available biomass in significant quantities below $20/dry ton farm-gate are heterogeneous wastes (Organic municipal solid waste, and urban tree residues)
  - Manure is potentially available in large quantities and at low cost, but off-site applications may be limited due to high transportation costs
  - Based on USDOE agricultural sector model projections[2], energy crops could be the largest source of biomass at prices in excess of $40/dry ton farm-gate, but energy crops are not currently produced in high volume
- Consistent and homogeneous biomass supplies are only available in large quantities at prices in excess of $20/dry ton farm-gate (e.g. energy crops, agricultural residues such as corn stover, wheat straw)
- The biomass sources with the highest potential in the 0-40 $/dry ton farm-gate price range are:
  - Corn stover (Great Lakes region: Minnesota, Iowa, Wisconsin, Illinois, Indiana, Ohio and Michigan)
  - Switchgrass (Southeast and West regions: all other states)
  - Organic municipal solid waste (Northeast: New England, New York, Pennsylvania, New Jersey, and Delaware)
  - Forest residues (Northwest :Washington, Oregon, Idaho, and Montana)
- Feedstock cost reductions are critical to enable broader competitiveness for most biomass technologies but feedstock cost reduction alone are not likely to be enough

Further cost reductions (through more efficient production and co-production with foods & feeds) could broaden the appeal of biomass use in industry.

1. For comparison for the industrial sector 2010 reference case: coal $1.3/million BTU; residual fuel oil is $3.4/million BTU; natural gas $3.3/million BTU in the EIA 2001 Annual Energy Outlook. The price of biomass is a farm-gate price; transportation of biomass is included in the costs of the various options.
2. Model results were obtained from Ugarte, D., M. Walsh, H. Shapouri, and S. Slinsky (July 2000), “The Economic Impacts of Bioenergy Crop Production on US Agriculture”. Additional resource references are in the Data Volume to this report.

Region specific data were generated for available quantities of all biomass types.

Cumulative Regional Available Quantities at 0 to 40 $/dry ton Farm-gate
Available Quantity, Million Dry Ton per Year

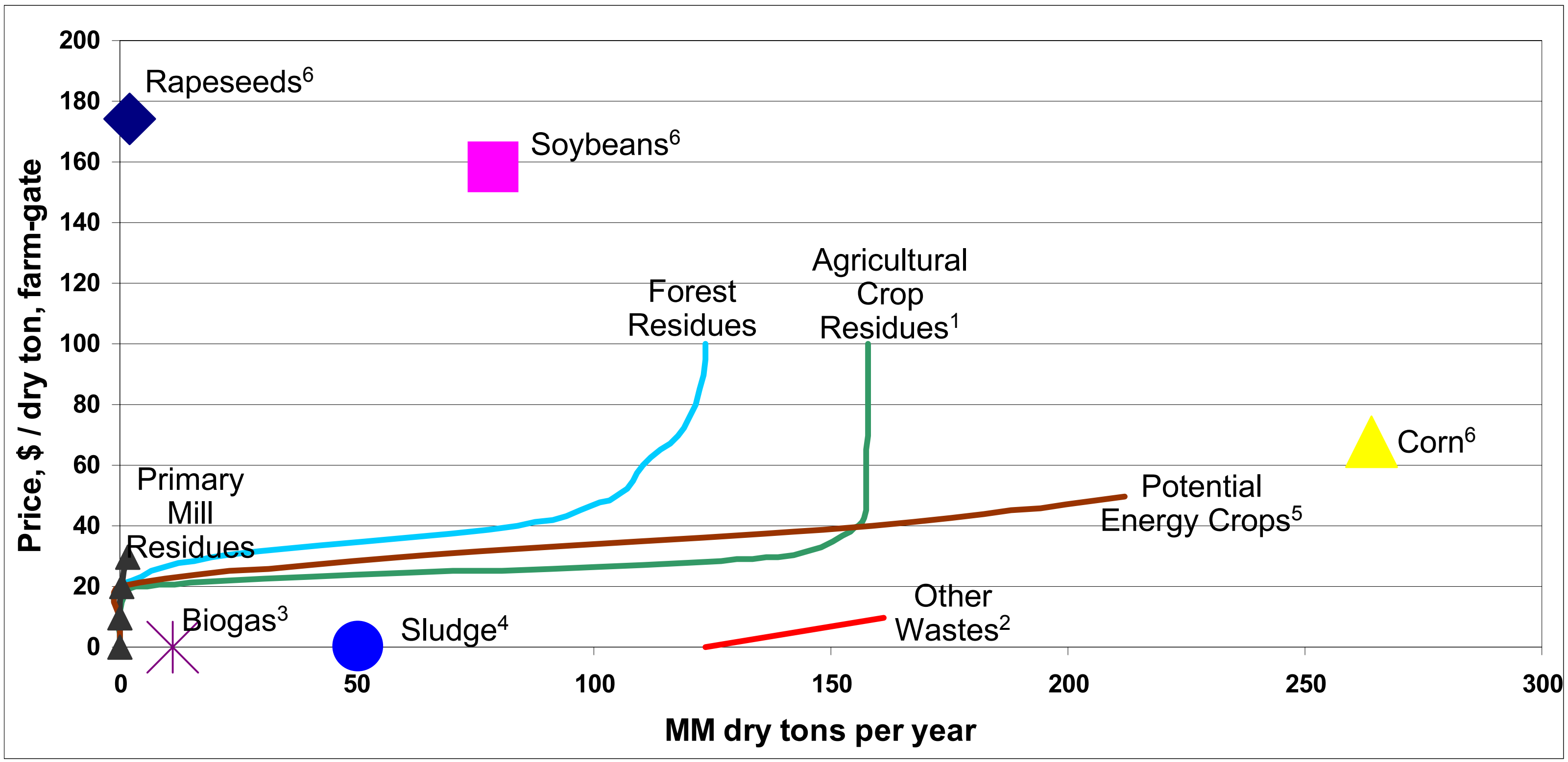


The regions are defined by the Regional Biomass Energy Program

1. Regions defined by Regional Biomass Energy Program: Great Lakes region: MN, IA, WI, IL, IN, OH and MI; Northeast: New England, NY, PA, NJ, and DE; Northwest :WA, OR, ID, and MT; Southeast: MD, WV, VA,NC, SC, GA, FL, AL, MS, LA, AR, MO, KY, TN; West: CA, NV, WY, ND, SD, NE, KN, OK, TX, NM, CO, UT, AR; Data did not include Hawaii and Alaska
2. Agricultural crop residues includes corn stover, wheat straw, rice straw, and cotton stalks.
3. Other wastes include the organic fraction of municipal solid waste, urban tree residues, and construction and demolition wood
4. Biogas includes landfill gas, digester gas, and sewage gas.
5. Sludge includes manure and bio-solids.
6. Potential energy crops include switchgrass, hybrid poplar, and willow.

Some biomass may be available at low cost, but most is expected to command prices in excess of $20/dry ton farm-gate.

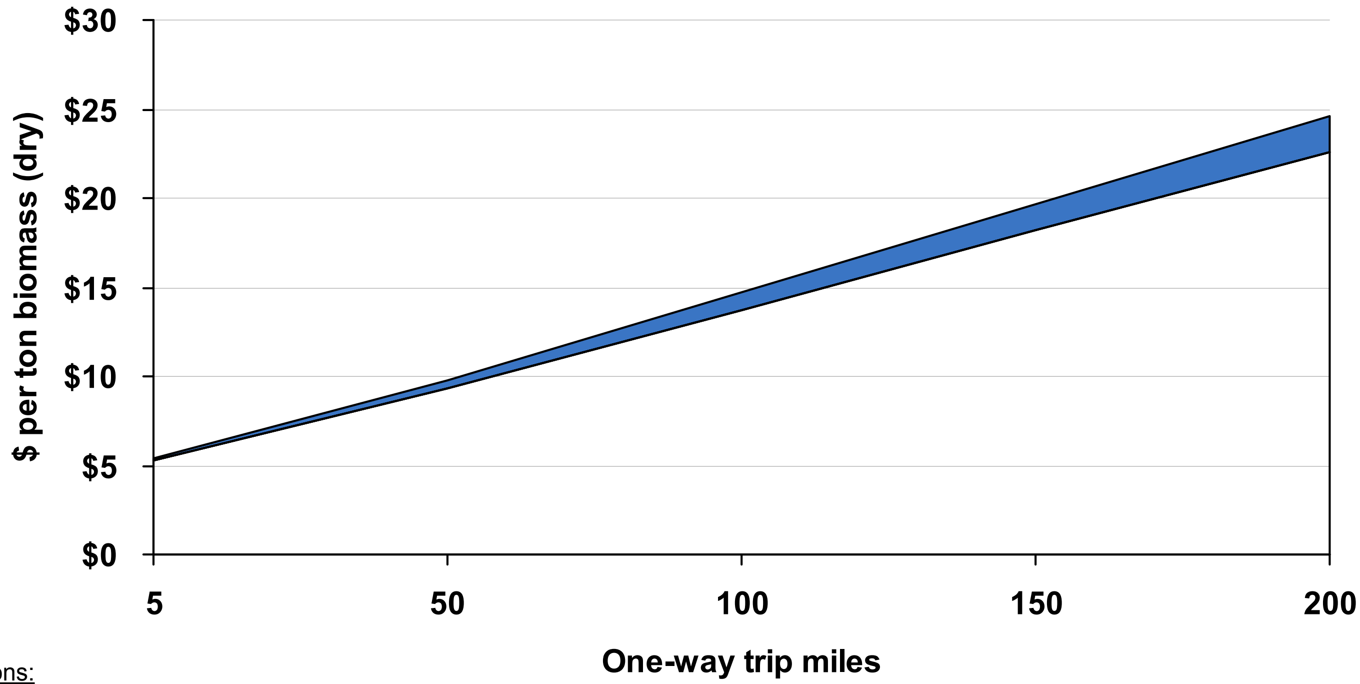
U.S. Available Biomass Supply Curve: Cost per Dry ton vs. Available Quantity
Million Dry Tons per Year, Farm-gate Price



1. Agricultural crop residues includes corn stover, wheat straw, rice straw, and cotton stalks.
2. Other wastes include the organic fraction of municipal solid waste, urban tree residues, and construction and demolition wood.
3. Biogas includes landfill gas, digester gas, and sewage gas. This analysis assumes all biogas is available at zero cost and is used on-site.
4. Sludge includes manure and bio-solids. We assume that all sludge is zero cost and used on-site.
5. Potential energy crops include switchgrass, hybrid poplar, and willow. Note that production was not evaluated above $50/dt.
6. A supply curve analysis was not done for traditional crops (corn, soybeans, and rapeseeds). Used the national average price and total quantity produced.

Transport costs of raw biomass may be a key factor in limiting the economy of scale achievable particularly for fuels and product production.

Example of One-way Transportation Costs of Dry Biomass, Dollars per Dry Ton



Assumptions:
6 miles/gallon average fuel economy (from Transportation Energy Databook, volume 19)
$0.92-1.35/gallon diesel fuel
$1,000 maintenance cost per year, + $20 oil change every 5,000 miles
$50,000/year driver salary, + $25,000/year benefits, driver operates truck 3120 hours/year (60 hour weeks)
5 miles of each trip at local speeds, remainder at highway speeds. 2 hours of each trip spent loading/unloading
10 year truck life, lease rate 8% per year with 10% residual value at end of lease (.131 capital recovery factor)
$113,000 truck capital cost, 29 ton capacity

For this study, the assumption made was 50-mile one-way transport.

Biomass production for new industries could provide environmental benefits, provided careful management practices are implemented.

- Converting traditional crop lands into perennial energy crop production could yield net benefits in increased soil carbon and nutrients
  - Energy crop production can have erosion concerns unless managed properly
  - Reduced runoff contamination and improved biodiversity are additional potential benefits
- If agricultural residue collection is managed properly, soil quality (e.g. organic matter, nutrients, and soil stability) can be maintained and/or improved and increased runoff contamination avoided
- Marginal lands (not currently used for crop production) need to be carefully managed to realize net benefits from energy crop production
- Forest residue collection must be managed properly to prevent erosion and realize benefits from fire prevention
- Several areas of additional research are necessary to assess the potential environmental impacts and benefits of bioenergy and bioproducts industries
  - The information currently available is based on smaller scale studies
  - Studies at larger scale are needed to validate results and determine landscape scale effects
- Carbon dioxide capture benefits are accounted for in the biomass end-use step in this analysis

Options both with short-term and long-term potential to approach the set aggressive goals were identified for each application category.

Application Category	Long-Term Potential to Achieve Aggressive Goals	Potential for Short-Term Implementation	Potential Biomass Use in 2010, Output Basis
Biopower	• Biopower plants based on advanced BIGCC(biomass integrated gasification combined cycle) • Biogas based power generation (e.g. landfill, sewage, digester gases)	• Biomass co-firing with coal • Biogas based power generation (particularly landfill gas)	• Additional 4400 MW or 0.14 exajoule (electric) for BAU over baseline of 10,000 MW • Additional 13600 MW or 0.37 exajoule (electric) for Aggressive implementation over baseline of 10,000 MW
Biofuels	• Broad use of bioethanol as a gasoline blend stock • Use of bio-FT-diesel as a diesel blend stock • Niche applications of each as neat fuels	• Use of ethanol as a gasoline additive and octane booster (bioethanol as MTBE replacement)	• Additional 800 million gallons ethanol for BAU (0.07 exajoules) over baseline of 1520 million gallons • Additional 2.3 billion gallons ethanol equivalent for aggressive implementation (0.2 EJ) over baseline of 1580 million gallons ethanol
Bioproducts	• Broad implementation of fermentation-based processes, primarily for polymer (feedstock) replacements	• Pyrolysis- or low-temperature processing-based options utilizing cellulosics and lipids, preferably integrated with an existing chemical plant • Fermentation derived polymer building-blocks	• Additional 600 million pounds in for BAU (~4200 TJ) over baseline of 21 billion pounds bioproducts • Additional 7.5 billion pounds for aggressive implementation (52,000 TJ) over baseline of 21 billion pounds bioproducts

TJ is 10^{12} Joules or 9.5E-7 Quads; 1.054 Exajoule (10^{18} Joule)= 1 Quad (10^{15} BTU)

Integration of these options could lead to “biorefineries” and could improve the long-term attractiveness of some of these options.

Several options for biomass-derived power and products appear to approach commercial competitiveness with their conventional counterparts...

- Some biomass options are approaching commercial competitiveness:
  - Biogas power (e.g. utilization of landfill gas) and biomass co-firing with coal are cost competitive in a broad range of geographic markets
  - Certain bioproducts are cost-competitive with their conventional counterparts and can offer performance advantages
- Bioethanol currently competes successfully in additive markets but currently relies on a significant ethanol fuel tax credit
- Feedstock availability is not a barrier to increased biomass implementation, but ready, consistent availability of low-cost feedstock would aid the economics and mitigate risks for investors:
  - Some feedstock is available at low cost now (and even at negative cost), which will help economics of some early entrants
  - As demand rises for high-impact applications, cost of feedstock is expected to become a significant factor and tipping fees will not likely be sustainable
- Nevertheless, the principal barrier to broader implementation of bioderived energy and products is the high production cost of almost all of the options:
  - Most green-field biopower options are expected to carry a net cost premium over natural gas-fired gas turbine combined cycle power generation of between 50% and 100%
  - Where biofuels are valued only on fuel energy content, they carry net pre-tax cost penalties of over 60% over conventional fuels (not taking into account the tax credit)
  - Despite significant advances in technology, many bioproducts appear to carry some cost-premium over fossil derived analogs

... but the production cost of biomass-derived energy and products remains the main factor limiting the ultimate potential for broad implementation.

From an initial list of over fifty options, ADL selected four classes of biopower for short and long-term implementation.

All biogas combustion options	• While the technical market potential is modest in size, the economic attractiveness of most options suggests that this "low-hanging fruit" is cost competitive now and should be developed wherever possible • Biogas includes landfill gas, sewage gas, and digester gas
Co-firing of solid biomass and of gasified biomass	• The economics are nearly competitive with wholesale power (but typically not with the marginal cost of coal-based power) • The large market potential could significantly contribute to the aggressive goals • This also retains utility-scale gasification technology in the mix of options
RDF Gasification	• Because the feedstock is potentially available at low to zero cost, the economics can be attractive • Because only a small fraction (~15%) of municipal waste is combusted for energy today, this leaves a very large untapped potential market • There are likely to be hurdles with respect to permitting and public resistance
Gasification of process wastes	• Where onsite waste fuels are available, gasification technology could be cost competitive, and have modest near-term market impact and significant long-term impact – Successful deployment of IGCC in the pulp & paper industry is critical to making this a high-impact option. • The cost of stand-alone biomass IGCC power for sale into the wholesale market is expected to be well above the cost of competing conventional technologies, but represents an enormous long term opportunity – Gasification, which will enable the long-term viability of new, biomass-only grid power, was retained for analysis in applications with better near-term economics.

Biomass co-firing at existing coal plants appears to be an attractive near-term option for biomass-based grid power.

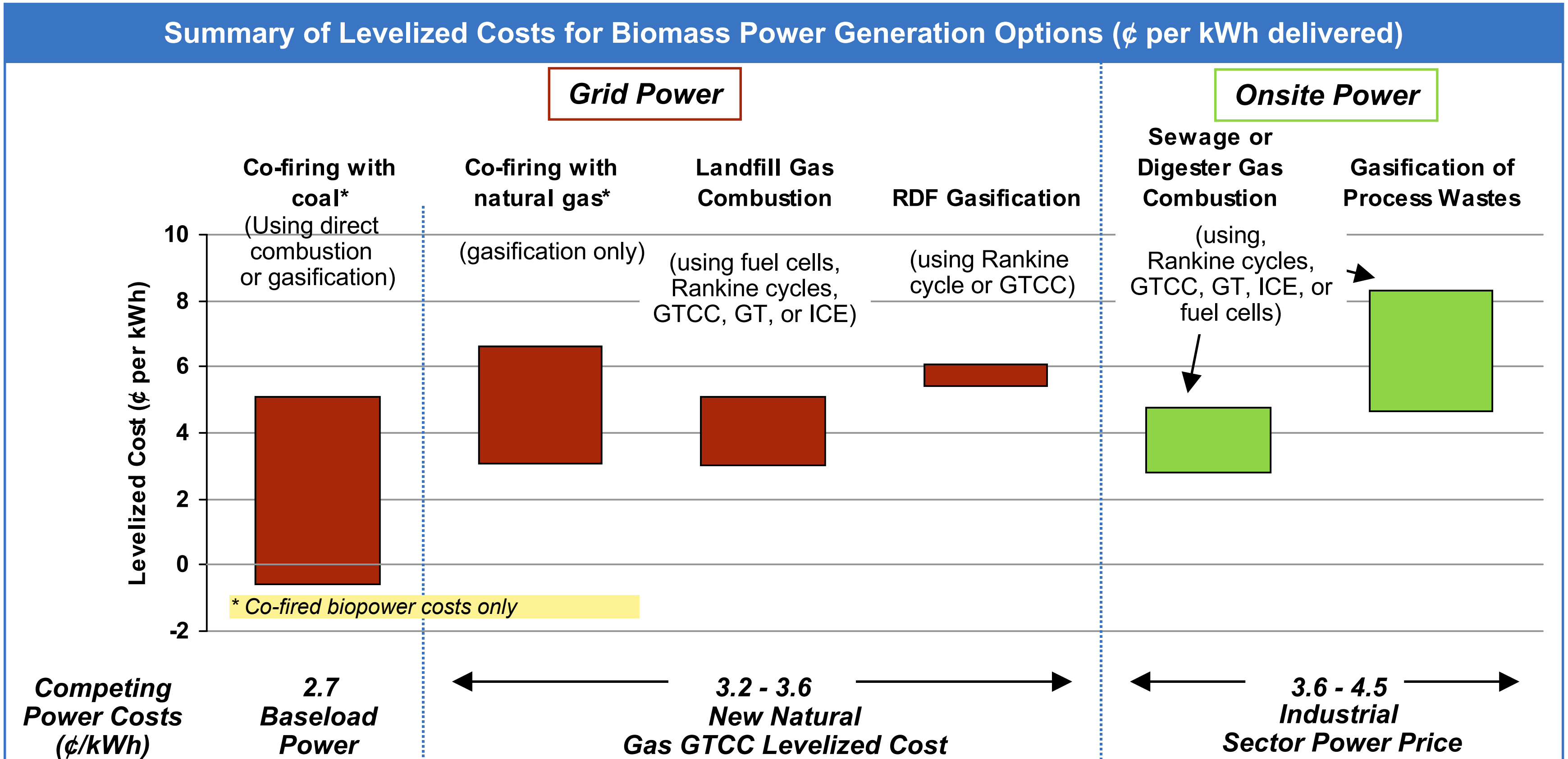
Advantages	Barriers
• Much lower marginal capital cost than new biomass-only power plants (\$50-500/kW vs. \$1,500-\$2,000/kW) • Emissions benefits at the coal plant (NOx and SO_2) have real economic value due to emissions trading • Able to take advantage of the higher efficiency of large coal-fired power plants (30-35%) compared to existing biomass-only power plants (15-25%) • Flexibility in biomass firing rates	• Fly ash regulations need to accommodate biomass content • Co-firing may trigger New Source Review requirements and may be incompatible with SCR for NOx control • Plant owners may perceive or encounter risks: – Biomass fuel price and availability relative to coal – Technical issues that could impact overall plant reliability and availability • Many coal plants are 30+ years old – the long-term future of these coal plants may be uncertain – Increased future interest in clean-coal technologies has the potential to offset the impact of retirements, at least partially.

- The United States has an installed coal-fired capacity of approximately 320,000 MW (more than 1,000 individual units)
- Biomass can be co-fired at rates of up to 10-15% on a energy basis, yielding a theoretical market potential for biomass of 32,000–48,000 MW
  - This is likely to be limited by biomass supply and other factors, but the potential is still significant

Co-firing with coal and utilization of biogas appear very attractive relative to grid and industrial power rates, provided that fuel costs are very low.

Assumptions and Methodology	• The costs shown are based on the levelized (all-in) cost of electricity (COE). The range in COE for a given application is due mainly to a range of feedstocks costs ($30-60/dry ton farm-gate for agricultural residues & energy crops; 0 to $30/dry ton farm-gate for process wastes (e.g. black liquor, hogged fuel, other solid residues); $0 - 0.50/GJ farm-gate for gaseous biomass); Detailed assumptions are in the data volume and in the biopower section • Results are expressed per kWh delivered. For grid-sited, this includes transmission and distribution energy losses of 7.2 percent, but not the actual costs of delivering the power • For options employing biomass co-firing with coal or natural gas, the economic calculations *are for the biomass portion only* • For biogas options (e.g. landfill gas, sewage gas, digester gases), the cost of generating and collecting the biogas is assumed to be accounted for outside the cost of power • Coal plants were assumed to be fully depreciated so that the cost of power from coal plants is effectively the marginal cost only. In order to better compare the levelized COE of biomass co-firing options to a similar grid option, data for electricity futures contacts were reviewed. Based on these data, 2.7¢/kWh was determined to be a reasonable cost for grid base load power
Comments	• Biomass co-firing has the potential to significantly reduce NOx emissions from coal plants, in addition to SO_2 reductions. These reductions were included in the levelized COEs, based on futures prices for NOx credits , and current prices for SO_2 credits. Co-firing in a natural gas GTCC does not produce emissions savings (other than CO_2), so there are no monetized credits for NOx or SO_2 included in the analysis • Although today some residues may have negative cost, for this analysis the minimum cost is assumed to be zero, a general assumption made throughout the study, consistent with the concept that as biomass utilization increases, residues that were once thought of as liabilities now have market value • For some industries, most notably pulp & paper, process residues are utilized for power and heat regardless of the power economics, because their use is integral to the core industrial process
Conclusions	• For grid-sited power plants utilizing solid biomass feedstocks, the cost of the biomass feedstock is an important component of total levelized costs • The range in levelized cost of electricity is from slightly negative for RDF and sewage sludge co-firing with coal to approximately 8-11 ¢/kWh biomass only Rankine cycle power for grid applications using agricultural residues & energy crops (not shown on plot of attractive options) • New, grid-based biomass-only power falls in the 7-11 ¢/kWh range for feedstock costs of $10-60/dry ton farm-gate using Rankine or IGCC technology (not shown on plot of attractive options) • Landfill gas and other biogas options appear to fall in the 3-5 ¢/kWh range, driven in part by very low fuel costs • Co-firing options appear the most attractive, due to low capital costs and in the case of coal, emissions credits

The lowest cost biopower options are co-firing with coal (due mainly to low capital costs) and biogas combustion (due mainly to low fuel costs).



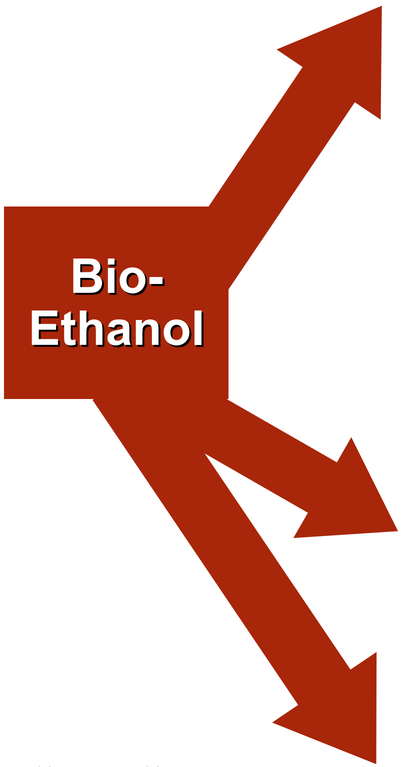
1. For co-firing cases, biomass is co-fired at a rate of 10 percent based on heating value. Natural gas is assumed to cost $2.90-3.47/MSCF.
2. Biogases such as landfill gas, sewage gas & digester gas; process wastes are generated and used onsite.
3. Co-firing with coal was compared to an estimated baseload wholesale cost of 2.7 ¢/kWh. All other grid power cases were compared to new capacity natural gas-fired combined cycle levelized cost of 3.2-3.6 ¢/kWh. Onsite power options were compared to industrial sector rates of 3.6-4.5 ¢/kWh (EIA *Annual Energy Outlook 2001*, Base Case price in 2010).
4. The analysis includes transmission and distribution energy losses of 7.2 percent for the grid power options, but not the actual electricity delivery costs.
5. Biogas costs range in price from 0-0.50 $/GJ; RDF & process wastes from $0-10/ton; agricultural residues & energy crops from $30-60/ton.

From an initial list of over 100 biofuel options, ethanol provides the economically most viable option for broad application.

- Currently, all biofuels are significantly more expensive to manufacture than petroleum fuels on an energy basis (e.g. dollars per million BTU energy content)
- Ethanol manufactured from corn continues to be a key current and near term option for oxygenates for MTBE replacement and octane blend stock
- Ethanol offers additional value in use as an additive and blend stock, respectively
  - Ethanol offers additive qualities which can increase its value far beyond its energy value, and can be cost-competitive, especially when considering the current ethanol fuel tax credit
- Bioethanol can be used as a blend stock in the existing fuel infrastructure

Ethanol	• Ethanol is attractive as an alternative additive to MTBE in reformulated gasoline or as an octane booster • Ethanol comes closest to cost-competitiveness with conventional fuels and there is significant experience with its use • Current and near-term demand is likely to be fulfilled by ethanol made from corn; cost projections of next generation SSCF cellulosic ethanol technology may make that technology competitive in mid around 2010

Ethanol is being used in three different modes, with its use as a gasoline additive being the economically most favorable one.



Gasoline Additive or Blend Market (Primary existing market with significant potential for near-term expansion)

- Current regulations limit blends to 10 percent by volume ethanol
- Higher concentration ethanol blends (likely up to 20%) are technically feasible
- Blended at 5 to 10% in gasoline by volume (typically 5.7, 7.7, 10%*)
- Works in conventional vehicles without any adjustments
- Provides octane improvement, emissions reduction, and a near-zero sulfur blend stock

Conventional Gasoline

- Ethanol value based on gasoline price with a premium based on ethanol's octane value
- Historically, ethanol is used as an octane enhancer and gasoline extender
- Suboctane gasoline for ethanol blending is now being produced in areas with high ethanol use
- E10 has an RVP waiver to compensate for its RVP increase in gasoline blends

Reformulated Gasoline (RFG) and Oxygenated Gasoline

- Clean Air Act requires a minimum oxygen content (Primary oxygenates are ethanol and MTBE; public acceptability of use of ethanol as ETBE is questionable)
- Value is based on oxygenate content (based on MTBE); minimum is based on competing MTBE prices
- Ethanol market will likely expand with an extended MTBE ban and continuation of oxygenate use in RFG
- Higher premium is possible if MTBE is phased-out suddenly resulting in an effective ethanol mandate
- Requires adjustment of summer RFG gasoline blend stocks to produce low vapor pressure gasoline
- May require more gasoline blend-stock; and may put more pressure on gasoline supply

Neat fuel (Existing, small market with largest potential size; least potential for expansion in near to mid term)

- Denatured with gasoline (e.g. Ed-85 in U.S.; Ed-95 in Europe); requires modest modifications to some vehicles, though new vehicles sold in the U.S. are increasingly fuel flexible, requires slightly increased maintenance
- Receives no premium over super premium gasoline (value based on heat content)

E-diesel

- Ethanol may also be used as a diesel oxygenate in e- diesel or oxydiesel (~10% vol ethanol; 5-10% other additives)

*5.7% and 7.7%vol are blends that correspond to the oxygen content standards for gasoline sold in ozone nonattainment and carbon monoxide nonattainment areas under the CAAA. Higher volume percentages needed for MTBE

Ethanol use as a additive provides an attractive biofuel option, which eventually could become cost-competitive without the tax credit...

Assumptions and Methodology

- Bars represent range of feedstock costs ranging from agricultural residue feedstocks to energy crops ($30 - 60/dry ton, farm-gate)
- We used EIA price projections for regular gasoline for 2010 and estimated MTBE prices based on these prices and the current premium of MTBE over regular gasoline (octane 89)
- Bioethanol is transported by truck, train, or barge (not pipeline) to blending terminals
- Assumed no vehicle modifications. Assumed no engine efficiency impact of biofuels

Comments

- Opportunity for increased use of ethanol as an additive is created by MTBE ban in California and other states considering MTBE restrictions
- The uncertain outcome of the MTBE debate creates uncertainty around this ethanol use option (e.g. continued MTBE use, complete MTBE ban, removal of oxygenate requirement; are all possible)
- In the long run, (post 2015) ethanol made from cellulosic-feedstocks could be cost-competitive without a tax credit with MTBE under most oil price scenarios, reducing the need for a tax credit
- In the near term the tax credit will be necessary under most oil price scenarios and provides a “cushion” for producers and buyers
- Potential for low-cost ethanol from corn will eventually be limited by markets for corn-mill co-products

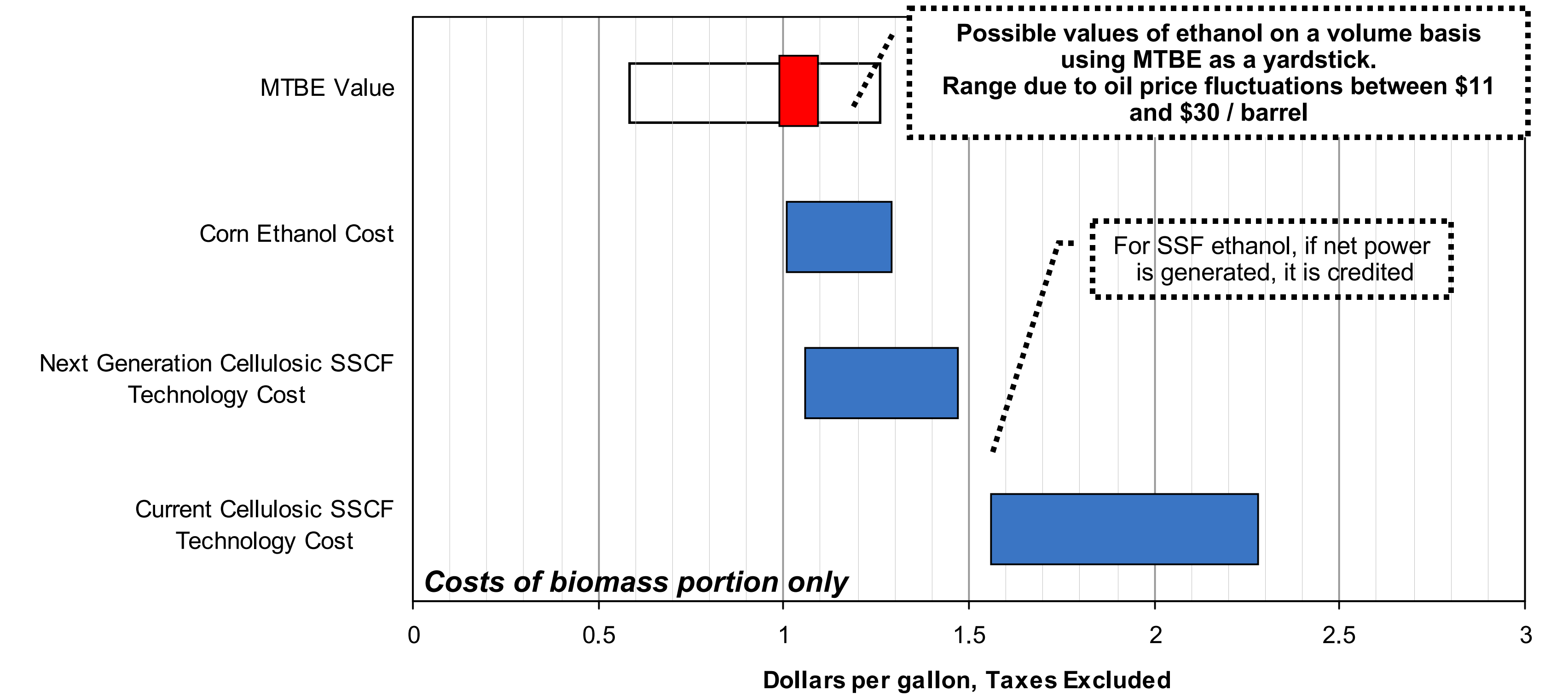
Conclusions

- Current starch / sugar-based ethanol provides a practical MTBE alternative under modest to high oil price scenarios with a tax credit
- Developmental SSCF technology could make ethanol production independent from food and feed production and possibly reduce the price differential in high volume, eventually perhaps obviate the need for the tax credit

... but in neat form would add significantly to the overall fuel cost.

Ethanol used as an additive commands a significant premium over its value based on energy content (~50 percent premium including taxes).

Levelized Cost of Ethanol as an Additive , $ per Gallon (Taxes excluded)



1. The bar range represents the spread of feedstock cost.
2. Corn ethanol price is based on ($1.5/bu with 2.8 gal ethanol yield per bushel corn) to ($2.9 per dry bushel corn with 2.7 gal ethanol per bushel); total chain cost.
3. The blended fuels are blended at a level of 10 percent by volume. The costs represented are for the biomass-derived fuel portion
4. The bar range of the SSCF options reflects feedstock cost of $30 to 60 per dry ton; farm-gate
5. SSCF is simultaneous saccharification and co-fermentationtechnology that utilizes cellulosics as the feedstock

Several bioproduct options appear to approach cost and performance parity with conventional petroleum-derived products.

Fermentation-Based Polymer Building Blocks

- Could offer cost-competitive routes to commodity plastics provided key technology challenges are met:
  - High primary product yield from substrate and high concentration in broth
  - Large-scale, continuous-reactor fermentation production technology
  - Ability to use low-cost feedstock (i.e. waste or inexpensive feedstock)
  - Offsite (e.g. Outside battery limit infrastructure) requirements that are similar to conventional petrochemicals

Pyrolysis- & Low-Temperature Processing-Based Products

- May be competitive in medium-sized markets:
  - Phenolics from wood pyrolysis for resin applications
  - Fatty alcohols from seed oils
  - Other lipid based products for lubricant & surfactant applications
  - Lipid-based feedstocks for polyurethane foam and coating applications

C1-Chemistry (Syngas) Based Products

- Do not appear to come close to being cost-competitive on a stand-alone basis
- Even though it is less attractive, there might be a need to consider it as a technology to produce co-products as part of a bio-refinery concept (e.g.in FT-diesel or dimethyl ether production)
- May require similar market premium or subsidy as current biofuels

Current bioproducts are derived from starch and lipids. Future growth may be through the use of cellulosics.

Starch & Sugars	Most current activity, especially for fermentation based processes, uses simple carbohydrates such as glucose as feedstock to make specialty chemicals and new polymer building blocks. The feedstocks are derived from food processing waste streams and pre-processed starches and are generally high in cost. For future high growth scenarios, research and development will be required to utilize more complex (and cheaper) feedstocks such as cellulose and hemicelluloses from cellulosic biomass
Lipids	Lipids are oils derived from plant and animal fats. Products have been used that incorporate the lipid as is but are limited in application. Typically the lipids are further processed by oil splitting and transesterification to produce glycerol, fatty acids,esters and alcohols. The ultimate market volume for lipid derived products may be limited by the supply of seed oils so that large scale application in some segments of the lubricant and surfactant market may be resource limited
Cellulosics	Cellulosics represent the feedstock with the largest potential volume for use for power generation, fuels production and chemicals production. For chemicals production, a key hurdle is using all constituents of the biomass (e.g. cellulose, hemicellulose, and lignin fractions). Research using the tools of biotechnology may enable broader use of the more recalcitrant fractions of the biomass (hemicellulose and lignin) for markets other than for power generation.

Trade-offs between the different types of process technologies are based on their inherent processing characteristics coupled with properties of the feedstock.

Physical Separation	Fermentation	Low Temperature Processing	Pyrolysis	C_1 Chemistry

← Increasingly takes advantage of biomass' inherent chemical structure. This typically helps the economics of the plant provided all fractions of the biomass (and co-products) have an end disposition

Increasing flexibility in product slate that can be produced. Therefore, increasingly likely to be able to cover large potential markets →

← Increasing impact of genetic engineering developments on process performance and product features

Increasing importance of system thermal integration for process performance and cost →

Fermentation based products for biomonomers appear promising if large scale continuous commodity processing can be achieved.

Assumptions and Methodology

- The plant-gate levelized product costs shown include the cost of the biomass feedstock, biomass transportation and primary product manufacture. Further costs for product transportation and distribution & marketing of the product or derivative manufacture/formulation are not included; it is a primary plant-gate cost.
- The range in the bioproduct costs reflect: for fermentation products the range of likely technologies used (batch and continuous bubble column technology); for pyrolysis products, plus/minus 30 percent of the plant-gate estimated cost; for low temperature process products, plus/minus 30 percent of the plant-gate estimated cost; for syngas derived products, plus/minus 30 percent of the plant-gate estimated cost
- The range of comparative prices for ethylene, caprolactum, and phenol reflect historical prices ~1990 to present with the current prices shown
- Green field plants are assumed. Plants using existing infrastructure were not analyzed

Comments

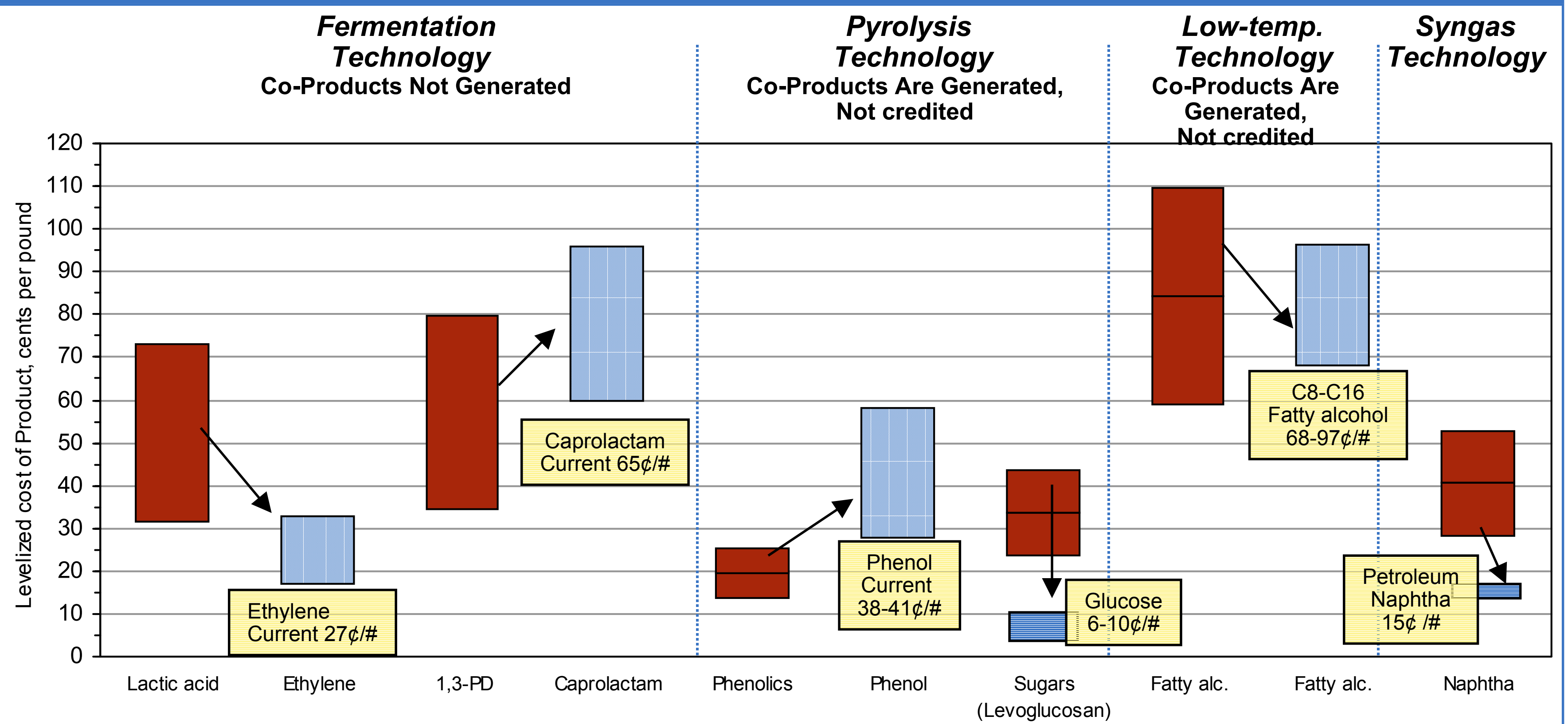
- The level of offsite investments has been estimated for each technology. Especially for fermentation based products, the level of infrastructure required for large scale commodity manufacture is an unknown. For example, investments for water treatment and investments required for microorganism containment should be further investigated
- The extent of economy of scale savings for fermentation based processes has been estimated for continuous processes using scaling methodology. The likely impact of increased scale on the total investment cost of the entire plant is an area of necessary attention since it will impact the viability of green field “biorefineries” which share infrastructure costs and produce a slate of products

Conclusions

- Fermentation processing for “biomonomers” appears promising if large scale continuous processing can be achieved which delivers cost savings from economy of scale
- Pyrolysis technology may be used to produce medium-size market products cost effectively (even at an advantage compared to petrochemicals). Additional costs may accrue from investments in product application & market development. Products such as sugars will likely be too expensive to be used as a fermentation feedstock
- Low temperature processes such as oil splitting are a mature technology and may be limited due to raw material availability and marketing of glycerol co-product
- Syngas processes based on biomass are likely to be too capital intensive for broad application on a stand alone basis even though it promises high flexibility towards the product slate

Bioproducts particularly using fermentation technology have potential to cost effectively compete as monomers.

Plant-gate Levelized Cost of Products, Cents per pound, Co-products Not Credited



1. The price of corn was $2.92 per dry bushel farm-gate. Wood for phenolics and levoglucosan is $50 per dry ton farm-gate. Seed oil is $0.17 per pound. Cellulosics were $30 per ton farm-gate.

Products using pyrolysis and low temperature (oil-splitting) are competitive today with sufficient raw material cost; market may be resource limited.

Biopower use could double by 2010 if a biomass infrastructure is established early, technology is developed successfully and strong government support is available.

- Biomass co-firing with coal provides the best options for rapid, near-term growth and is expected to account for over 50% of the growth until 2010
  - Direct co-firing using non-woody fuels (e.g. crop residues and grasses) will likely be required, which will itself require further technology development and demonstration
- Biomass integrated gasification combined cycle (BIGCC) technology in the pulp & paper industry is the second most important contributor with almost 20%of the growth through 2010, and with greater potential post-2010, provided the technology is adopted by the industry and cost is reduced
- Landfill gas and other biogases such as sewage and digester gas also figure prominently in the aggressive growth scenario for early growth
  - Technologies are available today
  - USDOE should focus on removing economic or regulatory barriers
- Other gasification options are less important in the near-term but are important for sustained growth:
  - Other industries that generate residues are expected to contribute modestly throughout the 2000-2020 timeframe
  - RDF could become a significant source of biopower in the long term, provided technical and environmental issues are addressed successfully
  - Gasification for co-firing could become significant beyond 2010, in both coal- and natural gas-fired power plants
- Implementation of the Aggressive Growth scenario would require several successful simultaneous developments:
  - Biomass supply infrastructure to develop rapidly if the market potential is to be realized
  - Successful development of gasification technology
  - Successful elimination of regulatory barriers to biopower implementation
- It would also require significant government support to overcome the cost difference of some longer-term options and expected market prices

In the desired "end-state", multiple biopower technologies are commercially available with some markets fully exploited.

2020[1] End State

Legend: Biomass Co-firing with coal; Gasification/IGCC; Biogases; Power in P&P; Regulations & Biomass markets; Small-scale Gasification

Co-Firing

Biomass co-firing with coal fully exploited at a variety of scales and firing percentages

10-15,000 MW co-firing in operation

Grid Power

Gasification-based technology is scale independent and low cost

RDF gasification fully accepted as viable option - commercially viable

Landfill gas fully exploited - 3,000 MW added

Onsite Power & CHP

Conversion technology is scale independent and low cost

Residues used for highest value application

5-6000 MW added in P&P through efficiency gains from gasification (black liquor, hogged fuel, bark, sludge). (Capacity added via increased biomass utilization for power only, which is part of the 2020 Vision of the pulp & paper industry, would be in addition to this amount).

Across market segments

Biomass infrastructure developed to deliver large quantities of biomass (energy crops, residues)

- Large companies involved
- Market mechanisms in place similar to other fuels (e.g., futures, B2B)

Common technologies between utility-scale IGCC are transferred to P&P industry for hogged fuel and bark residues

Common technologies between landfill, sewage and digester gases and other applications are transferred across market segments. Technology developments are applicable to biomass fuels and products applications

- Small-scale power generation
- Gas cleanup
- Low-medium Btu combustion systems
- Project development learning and business models (e.g., for many small-scale sites)
- Partnerships

1. We selected 2020 as the year to focus the vision to avoid missing attractive technologies that only barely achieve market introduction by 2010.

The aggressive growth scenario will require early technology demonstration combined with significant market and regulatory support.

Legend:
- Biomass Co-firing with coal
- Gasification/ IGCC
- Biogases
- Power in P&P
- Regulations & Biomass markets
- Small-scale Gasification

2002 | 2003 | 2004 | 2005

Co-Firing

- Specs for fly ash accepted - biomass content is OK
- NO_x Trading begins
- Special co-firing incentive to encourage early adoption - targeted to first 15-20 commercial plants
- U.S. demo of gasification co-firing in a coal plant
- Co-firing broadly accepted as green power - certification is given
- Solid co-firing with herbaceous biomass is as "easy" as with woody biomass
- Biomass fuel infrastructure responds to growing demand - large companies enter
- 1st commercial gasification co-firing in a coal plant
- 3000-5000 MW in operation
- Demonstration of gasification co-firing in GTCC

Grid Power

- U.S. demo of utility-scale biomass IGCC
- Aggressive development of Landfill gas projects begins
- Lack of landfill space renews interest in RDF conversion
- Standardization for Landfill gas projects streamlines development & reduces cost & shortens lead time
- EPA strengthens commitment to methane mitigation
- Microturbines deployed routinely for smaller Landfill gas projects
- Biomass-based green power is available/offered from new biomass capacity
- Advanced gas cleanup for turbines is proven
- 1st U.S. commercial utility-scale biomass IGCC
- Demonstration of gasification of RDF to prove environmental acceptability
- Market optimization occurs for use of biomass residues:
  - buying & selling ("residues.com")
  - onsite utilization (power vs. bedding, vs. mulch, etc.)

Continued electric and gas price volatility and regional supply/demand imbalances provides additional impetus for distributed power, CHP, and fuel diversity.

Onsite Power & CHP

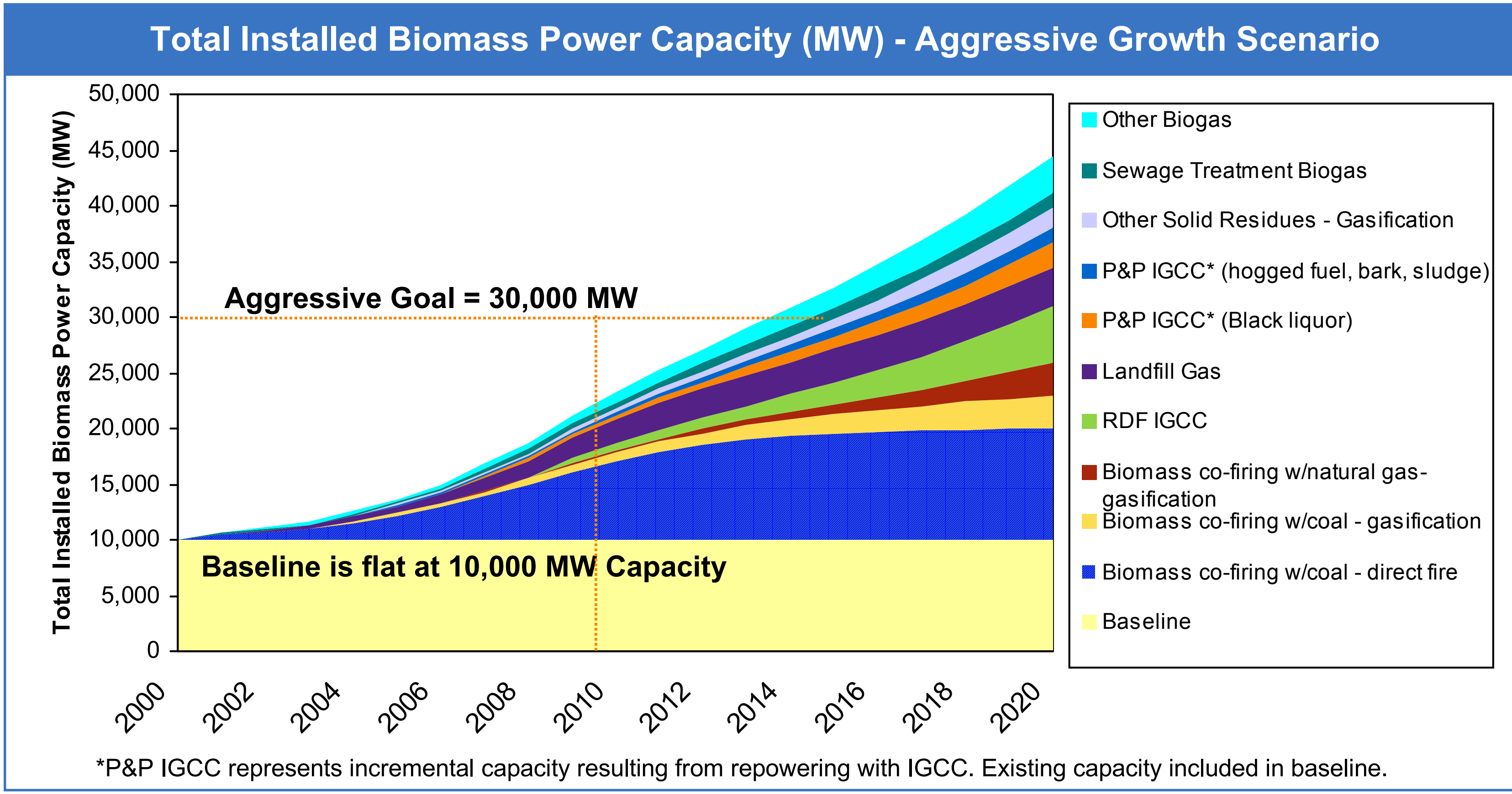
- Concern over impact of animal waste from CAFO on environment grows
- Next generation small-scale gasification systems
- Deployment of Digester gas conversion technologies accelerates
- Demo of IGCC using hogged fuel, bark & sludge
- Microturbines deployed routinely for biogas projects
- Chemical recovery hurdles overcome
- Multiple small-scale gasification systems commercially available:
  - multiple fuels
  - multiple technologies
  - scaleable
- Advanced gas cleanup for turbines is proven
- Black liquor gasification demo in full operation

To achieve the aggressive goal before 2020, continued improvement of technology competitiveness will be required.

Legend:
- Biomass Co-firing with coal
- Gasification/ IGCC
- Biogases
- Power in P&P
- Regulations & Biomass markets
- Small-scale Gasification

	2007	2010	2015	2020
Co-Firing	First commercial gasification co-firing in GTCC	6,000-9,000 MW in operation	10-15,000 MW co-firing in operation Best coal plant sites exploited - growth slows	Some conventional coal plants retiring - Co-firing may be decreasing Shift to co-firing with gasification in GTCC is accelerating
Grid Power	First commercial RDF gasification IGCC	Fuel cells running on Landfill gas are competitive relative to other biogas technologies Biomass IGCC deployment at multiple scales accelerates	RDF IGCC deployment accelerates (new and retrofit) $1000/kW or less for IGCC with > 40% efficiency Landfill gas fully exploited - 3,000 MW added	
Onsite Power & CHP	Commercial application of IGCC using hogged fuel, bark & sludge	Demonstrate that IGCC can generally replace Kraft boiler "on the fly" - minimal mill disruption during retrofit Fuel cells running on digester gas are competitive relative to other biogas technologies	Acceptance in mills to replace recovery boiler with gasification - deployment accelerates Digester gas fully exploited - 3-5,000 MW added Gasification of onsite residues 1-2,000 MW added	

Electricity from biomass could be tripled by 2015 provided that multiple feedstocks and technologies are exploited aggressively.

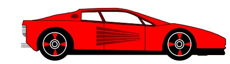


*P&P IGCC represents incremental capacity resulting from repowering with IGCC. Existing capacity included in baseline.

Provided biomass is available, growth is still possible after 2020 because some applications are still in relatively early stages of market penetration.

Biofuel utilization could be tripled by 2010, albeit at a significant cost.

- In a Business As Usual scenario, increases in production and use of biofuels would be approximately 800 million gallons ethanol by 2010 (above baseline growth):
  - Limited by current technology cost and government incentives
  - Gasification-based technology is not likely to become commercial
  - Ethanol looks like the preferred MTBE replacement but die is not cast
  - Implementation of ethanol as an MTBE replacement in California is thought to have net positive impact on California economy (but not necessarily on the country)
- Achieving tripling of biofuels use by 2010 would require:
  - Strong regulatory support for bioderived oxygenates for RFG nationwide
  - Highly successful technology development and cost reduction
  - Highly packaged plants for integration with conventional blending and distribution terminals
  - Continued and stable incentives for biofuel productions
- However, the cost associated with achieving this impact rapidly would be very high:
  - Cost of current bioethanol is supported by a $0.54 per gallon tax credit, higher than most other bioenergy support instruments
  - Achieving a tripling goal would probably require construction of cellulosic ethanol facilities based on first generation technology since markets for conventional corn-based ethanol co-products would be saturated



The vision for the aggressive growth scenario incorporates successful development of advanced technology combined with regulatory stimuli and incentives.

2020 End State

Ethanol

Greater than 750 million gallons of cellulosic ethanol
At least 10 plants in operation using cellulosic feedstocks

Medium-scale conversion technology integrated with blending terminals

Cellulosic ethanol primarily used in blending for octane enhancement and oxygenate content

FT-Diesel

Medium-scale gasification-based technology integrated with blending terminals

2 Demo FT-Diesel plants

FT Diesel demonstrated as low sulfur blending agent

Piggy back off biomass infrastructure developed to deliver large quantities of biomass (energy crops, residues) for co-firing

- Large companies involved
- JVs between fuel marketers and agro-companies
- Market mechanisms in place similar to other fuels (e.g., futures, B2B)

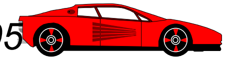
- Fuel specs require ultra-clean transportation fuels
  - Ultra-low sulfur
  - Low aromatics
  - Oxygenate requirement for diesel and gasoline
- Bio-blend-stocks receive preference over petroleum derived ones
- Green fuel premium is available for neat fuels in niche urban and fleet markets
- Alternative fuel status and tax credits are extended to other bioderived fuels other than ethanol

Gasification technology

Fermentation Technology

Market Issues

1. We selected 2020 as the year to focus the vision to avoid missing attractive technologies that only barely achieve market introduction by 2010.



Near-term milestones on the aggressive growth scenario timeline involve mainly technology development and fuel specifications.

	2002	2003	2004	2005

Ethanol

Successful pilot-scale demonstration of cellulosic SSF ethanol in several facilities

MTBE phase out in California
ETBE & TAME regarded similar to MTBE

SSF reactor worldscale scale-up demonstrated

Intensive CBP technology biotech program initiated

Integration of SSF ethanol with blending terminals demonstrated

- Feedstock markets becoming established
- Partnerships between fuels marketers and agro-business established

- Green fuels and blends marketing established in niche markets
- Ultra-clean fuel specs promulgated

FT-Diesel

Simplified FT based on biomass syngas test at pilot scale

Natural gas-based FT products accepted as blending agents and alternative fuels

Intermediate scale FT production demonstrated

Bio-FT-diesel approved for alternative fuel tax credit similar to current ethanol incentives

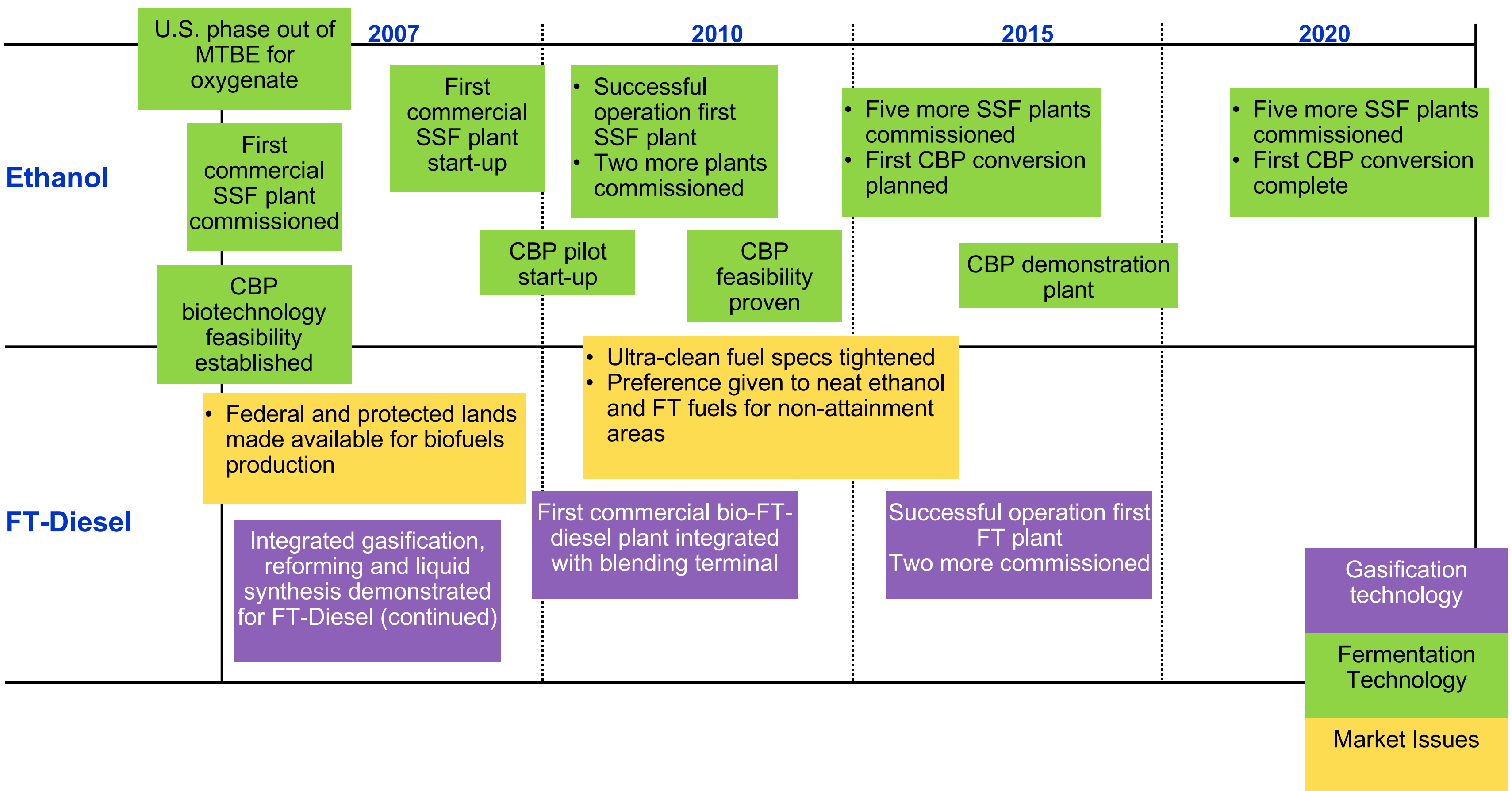
Integrated gasification, reforming and liquid synthesis demonstrated for FT-Diesel

Gasification technology

Fermentation Technology

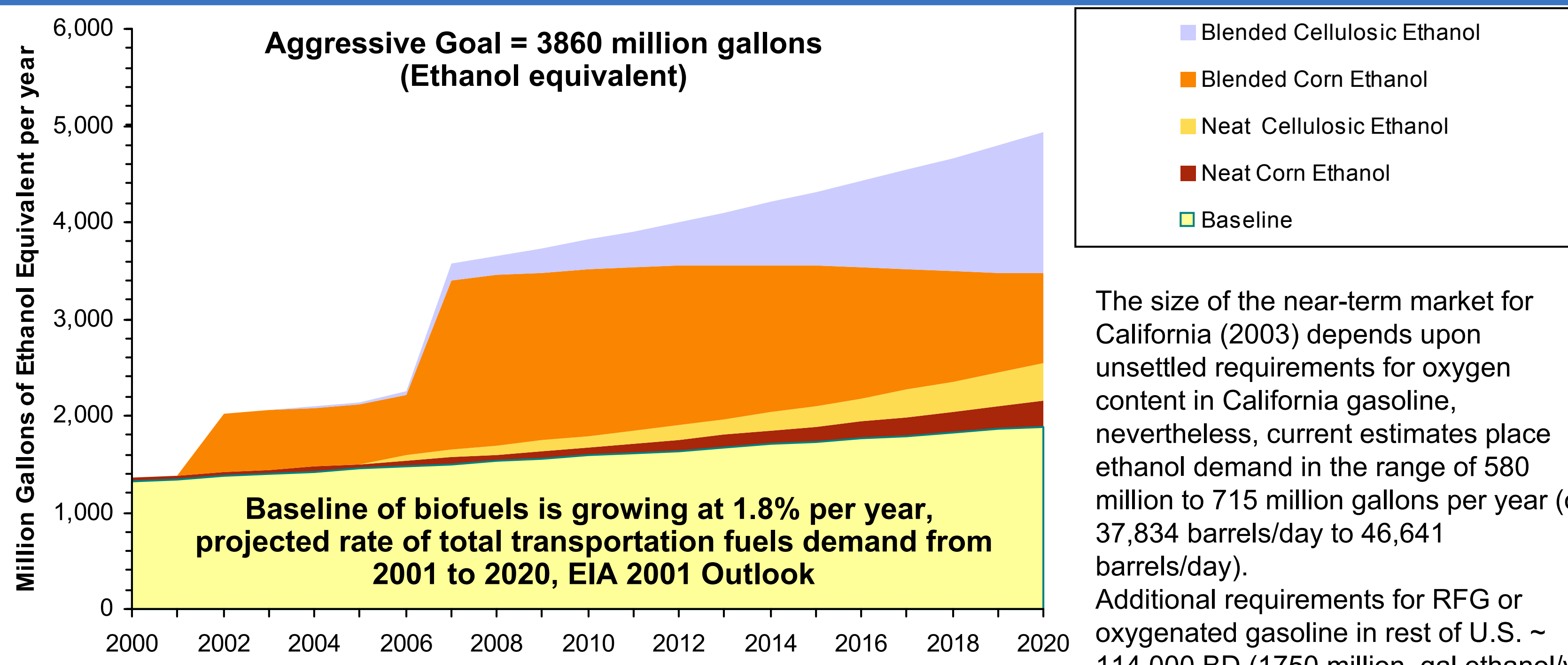
Market Issues

In the long term, sustained technology development and supporting regulation and incentives are critical to continued biofuels growth.



Biofuel production could technically be tripled by 2010 but this would require aggressive technology development and very rapid and significant new plant capacity investments.

Aggressive Growth Scenario, Cumulative Installed Capacity to 2020



The size of the near-term market for California (2003) depends upon unsettled requirements for oxygen content in California gasoline, nevertheless, current estimates place ethanol demand in the range of 580 million to 715 million gallons per year (or 37,834 barrels/day to 46,641 barrels/day).
Additional requirements for RFG or oxygenated gasoline in rest of U.S. ~ 114,000 BD (1750 million gal ethanol/y)

SUPPLY AND COST OF ALTERNATIVES TO MTBE IN GASOLINE, TECHNICAL APPENDIXES, Technical Documents, California Energy Commission, 1998, prepared by Purvin & Gertz, Inc.

Growth may be limited due to the time and infrastructure (and investment) required to build the new plants and possibly feedstock availability.

Bioproducts use could be tripled by 2020 requiring aggressive technology and market development but not sustained government support.

- In a Business as Usual scenario, bioproducts would capture a small fraction of the growth volume of specific chemical markets
  - No current large-scale incentives for bioproduct use (such as tax credits for ethanol fuel, green power and other renewable power credits)
  - Most of the growth comes from traditional bioproduct growth (e.g. starches) and from products produced by physical extraction (e.g. seed oils), in which bioproducts already have a high market share
  - Limited potential market for low-hanging fruit
  - Technologies with greater potential impact do not reach the market until much later and will penetrate the market slowly
  - Even in the BAU scenario, however, we expect bioproducts to have a considerable impact in the longer term, since competitive economics will be achieved for broad-based application of bioproducts to polymers and solvents
- With aggressive technology and market development and some government support (but not necessarily product price support), a significant impact (even tripling) may be achievable by 2020, though not by 2010
  - Technologies with high impact potential (such as fermentation-based polymers and monomers) would become commercially available in the 2010 timeframe
  - With plant construction and market penetration inertia significant market penetration would not be achievable before 2020
- Given the limited volume of product markets (as compared with fuels and power markets) the relative impact of bioproducts on greenhouse gas emissions and rural economic development can be considerable, but not large in absolute terms
  - Because of the more limited scale, at least early facilities may well be integrated into existing chemicals plants or into existing corn or paper mills
  - The projected economics of bioproducts will eventually not require sustained government financial support for several of the options, resulting in potentially very modest cost for investment, but not for sustained subsidies

The aggressive scenario focuses heavily on successful development, demonstration, and implementation of fermentation-based technology.

2020 End State

Commodity Bioproducts

Greater than 750 million gallons of cellulosic ethanol
At least 10 plants in operation using cellulosic feedstocks

Conversion technology is scale independent and low cost

- Bioproducts are seen as "Green" with enhanced properties that can carry a price premium
- Bioproducts will compete with petroleum products that are biodegradable which is also viewed as "Green"
- EPC industry has developed a new market, construction and operation of large scale bio-processing plants

Piggy back off biomass infrastructure developed to deliver large quantities of biomass (energy crops, residues) for coal co-firing

- large companies involved
- market mechanisms in place similar to other fuels (e.g., futures, B2B)

An incremental 20 billion pounds of material derived from biomass is being produced per year in 2020. Most of the new capacity will leverage fermentation technologies. Growth will continue to leverage existing and new uses for ag products such as seed oils. High temperature processes using cellulosics make specialty products for small to medium volume applications.

The consumers drive the demand for products seen as green.

The processing technology for bioproducts has been significantly improved and seen as clean. Biomass plants are no longer viewed similar to a MSW incineration plant.

Products are:
- Solvents
- Polymers
  - –Propanediol polyester
  - –Lactic acid
- Other organic acids such as citric, succinic
- Paints & inks
- Detergents
- Specialty Chemicals
- Adhesives/Sealants/Coatings
- Polyurethane intermediates (polyol)

Specialty Products

Bioproduct Technology Developments

Biofuel Technology Developments Leveraged

Biopower Market Development Leveraged

Bioproducts leverage the aggressive advances made by biofuels and biopower.

1. We selected 2020 as the year to focus the vision to avoid missing attractive technologies that only barely achieve market introduction by 2010.

In the short term, the aggressive scenario will require a mix of aggressive technology development and facilitation of bio-engineering from a regulatory perspective.

Legend:
- Commodity Technology Developments
- Biofuel Technology Developments Leveraged
- Biopower Market Development Leveraged
- Specialty Technology Developments

2002 | 2003 | 2004 | 2005

Commodity Bioproducts

2002

- Current likely fermentation-based commodity bioproducts are made with simple starch & glucose feedstocks obtained from dedicated & waste streams (e.g. corn mill and food processing waste streams)
- Future fermentation-based bio-commodities may have to use dedicated high-volume cellulosic feedstocks. Programs are put in place to leverage experience gained with cellulosic ethanol organism design

Studies on possible cost savings of co-locating bioproduct plants near existing chemicals, refining, resource, & grain mill plants. Identification of possible shared infrastructure.

2003

Demonstration semi-works plant runs for SSF ethanol technology are conducted

Improved reactor designs for continuous commodity scale fermentation processes at bench to pilot scale

R&D and pilot studies continue with varied feedstocks (e.g.agricultural residues, energy crops, woody feedstocks, MSW) to develop operating windows for optimal microorganism (MO) performance using existing metabolic pathways

Develop policy instruments to encourage growth of new resource industry to supply glucose; make glucose the bio-industry "ethylene"

Commodity lactic acid commercial plant on-line

Study on what are the likeliest products that can be derived from existing metabolic pathways Create a wish list of possible "building blocks" that could be made with "to be designed" metabolic pathways

2004

Biomass-based green power is available/offered from new biomass capacity

Engineering MO to make glucose (or derivatives) as feedstock Inter-agency coordination and cooperation on bioproducts development/ road map

1,3-propanediol (1,3-PD) from glucose semi-works plant on-line

Advanced gas cleanup for turbines is proven

Biomass resource infrastructure responds to growing demand for biopower- large companies enter

2005

Bio-Polymers are a hit for disposables. "Cheap and Green" has resounded with the market

Start programs that encourage long-term research on utilizing hemicellulose and lignin to produce commodity high-value products. Long term research to use cellulose as feedstock to provide glucose source

Lactic acid plant-2 online at existing site

Co-ordinate with NIH and NSF for long-term research for new metabolic pathways for promising future "building block" chemicals

Market optimization occurs for use of biomass residues:
- buying & selling ("residues.com")
- onsite utilization (power vs. bedding, vs. mulch, etc.)

Specialty Products

Lessons learned from biopower gasification enable use of syngas based products as part of a biorefinery concept (stand-alone plants not likely to be competitive)

Specialty products derived from seed oils, fermentation processing, and high temperature processing will continue to be developed when the delivered performance and cost offers advantages over competitive petroleum derived products

External instruments will continue to influence the adoption of bioproducts. For example halogenated solvents may be gradually replaced by alternatives that offer price competitiveness and enhanced properties

Additional resources may be required for application development, market development, and necessary infrastructure investments

In the long term, the aggressive scenario will require continued focus on technology development combined with considerable consumer education and leveraging with fuels and power applications.

2007 | 2010 | 2015 | 2020

Legend:
- Commodity Technology Developments
- Biofuel Technology Developments Leveraged
- Biopower Market Development Leveraged
- Specialty Technology Developments

Commodity Bioproducts

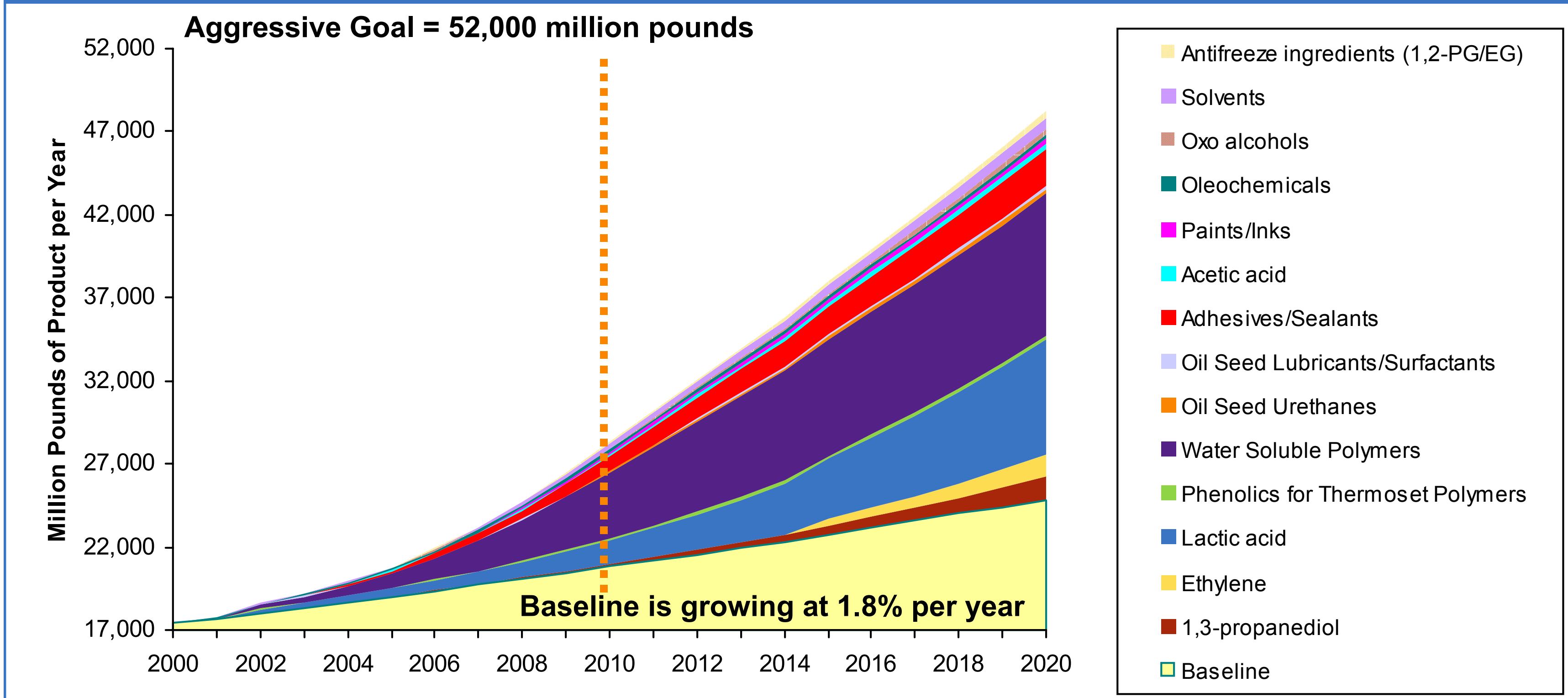
- First commercial gasification co-firing in GTCC
- Commercial scale plant (~75 million gal/yr) on-line for SSF cellulosic technology
- Market for lignin for biopower applications established. Uses biopower resource delivery infrastructure
- Aggressive construction schedule to keep up with projected demands, cost competitive with EO derived 1,3-PD. 4 new world scale plants (~300 million lb/y) through 2020
- 11 Commercial scale SSF ethanol plants on-line
  Market for co-products expanded
- First commercial plant for 1,3-PD using glucose, ~200 million lb/yr gradually expanding production through ‘12 Improvements through experience are reducing cost towards competitiveness with EO derived 1,3-PD.
- Cellulosic ethanol enables bio-ethylene from ethanol. Aggressive capacity put in place, 1 billion pounds by 2020
- First green-field world scale commodity lactic acid plant online
- Aggressive construction and engineering efforts to keep up with projected demands. Projected demands require building and getting up a plant every year through 2020. Plants with multiple trains located near central resource gathering places. Projected demand of 7 billion pounds by 2020.
- Pilot scale demonstrations of continuous processes using cellulose to make glucose to leverage existing metabolic pathways
- Pilot scale demonstrations of continuous processes using hemicelluose to make glucose to leverage existing metabolic pathways
- Proteomics is leveraged to map new metabolic pathways to produce designer molecules with distinct functionalities for both pharma, specialty, and commodity markets
- Pilot scale studies with new designer metabolic pathways found with aid of existing work with proteomics

Specialty Products

- New markets for glycerol are developing, possible co-feed for bioproduct syntheses
- New product applications and markets are developed using existing biomass sources, mainly ag-products and food waste streams. Cellulosics are being used more and more for new product applications. High-volume applications are identified for possible high volume manufacture

The aggressive scenario reaches over 50% of the aggressive goal by 2010 and almost reaches it by 2020.

Aggressive Growth Scenario, Cumulative Installed Capacity to 2020



The scenario includes an aggressive plant construction schedule for fermentation-based processes, which will probably have to be combined with SSF ethanol production.

Rapid increases in bioenergy and bioproduct use would carry significant investment and operating costs to the country.

Application Category	Economic Benefits & Impact
Biopower	• At a national level, the incremental cost of implementing biopower could be on par with COE of new capacity natural gas-fired GTCC by 2010 provided that a significant amount of capacity is used with very low cost feedstocks (e.g. process wastes at zero cost). In the BAU scenario: 2500 MW are in co-firing with coal using existing capacity; ~1850MW are associated with zero cost gaseous biomass and zero cost process wastes. In the Aggressive scenario: 210MW in co-firing with NG GTCC; 7800 MW in co-firing in coal plants; 1015MW for RDG gasification; and 4540MW in utilizing zero cost gaseous biomass and zero cost process wastes • This would not be off-set by reduced imports, as biomass would predominantly replace domestic coal and natural gas resources • For co-firing, the vast majority of economic activity will occur in rural areas
Biofuels	• At a national level, the incremental cost of implementing increased biofuels could reach ~$130 million to $500 million by 2010 not including any tax credit and provided ethanol for blending commands value equivalent to MTBE on a volume basis. This cost is partially off-set by increased tax revenues and other benefits of increased economic activity in the U.S., due to reduction in oil imports • Ethanol may serve as a leading oxygenate replacement additive for MTBE as other ethers (TAME, ETBE) may find similar resistances as for MTBE and alcohols such as TBA may be capacity limited in the short term • Biofuel production will significantly benefit rural areas
Bioproducts	• On average, the incremental cost of bioproducts over conventional avenues to the nation is moderate, due to the modest cost premium. Biomass feedstock cost is less a driver for bioproducts at this stage of development. Capital cost and operating cost reductions will greatly increase the competitiveness of bioproducts when compared to fossil-derived analogs • Though some of the bioproducts options are ultimately economically attractive, they require significant up-front investment • The benefits for rural communities are modest, as most economic activity is likely to take place in processing plants which may be placed in semi-rural areas

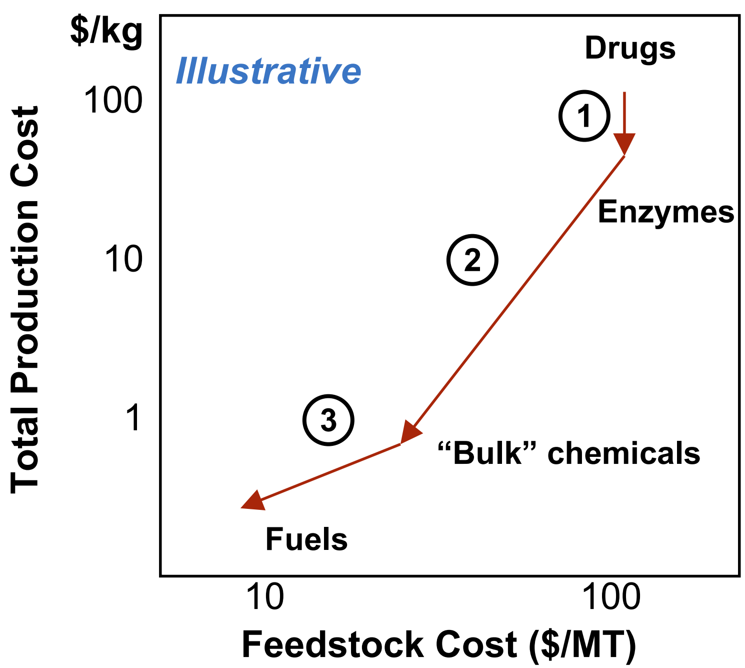
Technology development has the potential to significantly improve the performance of biomass technologies...

- Performance improvements include:
  - Higher efficiency of conversion (e.g. direct combustion to integrated gasification combined cycle)
  - Use of lower cost feedstock (e.g. processed starch to cellulosic)
  - Improved and demonstrated reliability and safety (e.g. black liquor gasification)
- The time required for technology development and commercialization is often underestimated and is expected to limit the rate of implementation of biobased products, fuels, and power:
  - Technology development for industrial conversion processes from pilot to fully commercial scale typically takes about three to five years, five more years can be added for bench-scale development
  - Especially for chemical and derivative products (e.g. Polymers, additional development time will be required for application and market development)
  - Achieving complete market penetration following market introduction typically takes twenty to forty years for capital-intensive processes such as fuels or power production, slightly less for chemicals
  - The time period of market penetration may change with modular technologies

... but timeline for technology development and industry inertia are the main factors limiting the rate of implementation.

Reduction of production cost through cuts in feedstock cost, improvements in primary conversion, and success in scale-up are all key to mass market penetration.

Required Production Cost Reduction



1. Reduction of cost by scale-up of existing processes is required to minimize capital and operating costs (e.g. ADM world-scale wet corn mills)
2. Fundamental primary conversion process improvement is the most critical step (e.g. Cargill-Dow LLC lactic acid development):
   - Improved product yield
   - Higher product concentration
   - Higher selectivity
   - Increased feedstock flexibility
3. Additional reductions in feedstock cost will be required to meet cost-targets for fuels and certain high-volume chemicals (e.g. possibly through genetically engineered crops)

Processing in a "biorefinery" may reduce the overall production cost and allow for the production of "premium" products with high value but small market volume.

Typical times for each aspect of technology development and commercialization will limit the rate of market penetration of new biomass-derived energy and products.

Technology *(basic materials, working principles)*	First Evidence	Technology Viability	Technology Verification	Advanced Development	Commercialization
	8-15 years	5-10 years	3-8 years	1-4 years	0-2 years
Production Process *(process to manufacture technology)*	First Evidence	Proof of Principles	Unit Operation Development	Process Integration & Demonstration	Commercialization
	8-15 years	5-10 years	3-8 years	1-4 years	0-2 years
Product *(Product incorporating technology)*	First Evidence	Product Concept Viability	Product Design	Advanced Developmen t	Commercialization
	2-15 years	2-15 years	1-4 years	0-1 years	0-0.5 years
Market *(Customers that want to buy products)*	Customer Need	Product Idea Development	Product Concept Development	Product Refinement	Initial Product Launch
	2-6 months	1-6 months	1-6 months	2- 12 months	2-8 months

Market Penetration

Depending on the product; market development may require longer times; in the order of double to triple shown

In order to facilitate the overall process, these developments must take place in parallel: the U.S. government can help guide and coordinate this process.

A number of uncertain factors could considerably benefit or detract from the growth and impact of biomass-derived energy and products.

- Conventional energy prices:
  - Developments in ***crude oil prices*** are likely to have considerable impact on all options, particularly on the fuels and products options, which are competing directly with petroleum-based products
  - ***Gasoline shortages*** in 2000 due in part to localized rulemaking leading to boutique fuel requirements provide an opportunity for biofuels
  - Uncertainty in ***natural gas and electric power prices*** also could have a significant impact on bioenergy viability, particularly for biopower options
  - Fluctuations in prices cause uncertainty which concerns investors in biomass plants
- Political factors:
  - The situation around ***RFG oxygenates (MTBE)*** is unresolved and though it currently appears favorable for biofuels, other outcomes are still possible
  - ***Tax incentives for biofuels*** have been rather stable over the past fifteen years
  - Discontinuation of PURPA support for biopower plants has caused concern over long-term reliability of government support
- Public opinion:
  - Public environmental concern drives most interest in biomass-derived energy and products
  - Until recently ***use of Genetically Modified-crops*** for non-human food-uses was considered uncontroversial in the U.S., but experience with GM-corn crossfertilization has called this into question; this could have significant ramifications for the feasibility of certain crop improvement efforts for energy and product applications
  - NIMBY concerns for waste to energy facilities might affect RDF biopower options
  - Impact of biomass production/collection/transport on local environment may be a concern

Bio-refineries where true synergy between production processes can be achieved, deserve additional attention.

- Combining biomass-based processes into “Bio-refineries” can offer two potential benefits:
  - Maximizing the value of the products per ton of feedstock (for combining biomass-derived processes only)
  - Maximizing the economy of scale of the overall process (for combining biomass-based with fossil-based processes)
- “Bio-refineries” that do not involve any synergy between the production processes may be attractive in some cases, in which case, they will be implemented readily
- “Bio-refineries” that do offer direct synergy between the production processes offer greater potential benefit, but are also more complex and are not well-understood
- The U.S. government could further support the study of such synergistic bio-refineries, but should focus on realistic options

Bioenergy and bioproduct industries could provide environmental benefits, provided careful management practices are implemented in biomass production.

Application Category	Environmental Benefits & Impact
Biopower	• Due to the very large potential market, carbon dioxide reduction benefits on the order of 26 to 80 million tons per year can be expected by 2010, especially since efficiency of biopower compares well with conventional power • SO_2 and NO_x emissions could also be significantly reduced, especially in co-firing with coal • In other cases, SO_2 and NO_x impacts vary drastically, mainly depending on the type of conversion technology and the appropriate conventional alternative power option • Methane emissions are cut in biomass co-firing with coal
Biofuels	• Due to the large market potential, carbon dioxide reduction benefits of over 5 to 14 million tons per year can be expected, even if ethanol use as an additive is the primary mode of use • Use of ethanol as an MTBE replacement could provide similar NOx, CO, and HC benefits as MTBE, but without the groundwater contamination concerns • When ethanol is used in pure form, the emissions benefits will likely be traded off against engine performance and cost by automotive original equipment manufacturers where possible
Bioproducts	• Carbon dioxide reduction benefits of bioproducts are more modest (120 to 1300 thousand tons per year, due to the smaller overall volume of the chemicals markets) • Criteria pollutant emissions benefits are modest as well

Relative to the appropriate competitive power option, biopower offers the greatest emissions benefits for CO_2, SO_2 and, in some cases, NO_x.

- In all cases CO_2 reductions (per kWh) are significant, ranging from 65-100%
- Except when compared to natural gas GTCC, biomass power results in significant SO_2 reductions (80-97%)
  - Biomass is generally much lower in sulfur than coal
  - In some processes (e.g. gasification) sulfur removal to very high levels is possible
- NO_x benefits are more mixed, and generally are technology (versus fuel) dependent
  - Natural gas GTCC technology sets a very high standard for NOx (Low generation levels),
  - Biogas-fired (including landfill gas, sewage gas, & digester gas) GTCCs are expected to have similar NOx benefits depending upon the nitrogen content of the biogas
  - Biomass co-firing with coal has the potential for significant NOx benefits (e.g., 20% overall reduction for 10% co-firing)
  - Reciprocating engines produce levels of NOx comparable to or greater than the grid average unless special control equipment is used
- Emissions of CH_4 are reduced with biomass co-firing with coal by avoiding coal production emissions of methane
- Emissions of non-methane hydrocarbons and carbon monoxide, are generally unaffected by the use of biomass as a fuel
  - Fugitive NMHC, & PM emissions that would have occurred regardless of the end use were excluded
- Advanced biopower conversion technologies should produce particulate matter (PM) reductions
  - All technologies that convert biogases produce less PM than the grid average
  - Co-firing biomass options do not produce PM reductions
- The solid waste and water effluent impact are expected to be moderate and manageable
  - Most biomass is low in ash and in most cases, the ash is non-toxic and can actually have value as fertilizer
  - Water effluents can contain suspended solids and biological oxygen demands but toxicity is not usually a serious concern

A life cycle analysis of the environmental impacts was not included in this study.

Biofuels can offer tremendous carbon dioxide reduction savings compared to petroleum fuels even when used as primarily a blending agent.

- Biofuels offer the only remotely affordable option to drastically reduce CO_2 emissions from transportation fuel chains
- When used as an oxygenate in RFG, ethanol could play a critical role in criteria pollutant emissions reduction
- Without legislative protection of the clean fuel benefit of biofuels when used as a neat fuel, these benefits may be lost in re-optimization of engines for power or cost
- The solid and water effluent waste is expected to be manageable
  - Solid wastes are expected to be biodegradable and usable as fuel (e.g. Cell mass)
  - Water will contain suspended solids and toxicity is not a serious concern
  - Water use for processing (especially for fermentation) may be a concern in arid or semi-arid regions
- Production costs for biofuels are around 25-60% more than those of conventional additives, however, tax credits are currently off-setting this difference
- In the long term, the cost of ethanol use could be largely off-set by the benefits of local production (in the U.S. vs abroad)
- About half of the economic activity involved in ethanol production is likely to occur in rural areas as a large fraction of biofuel cost is in the feedstock

The benefits of bioproducts can be significantly increased at a modest ultimate cost to the nation.

- CO_2 emissions of bioproducts could offer significant benefits but the absolute amount is somewhat limited by the size of chemicals markets
- Criteria pollutant emissions are not strongly impacted by the implementation of bioproducts
- The solid and water effluent waste is likely to have the same issues as for cellulosic ethanol implementation and is expected to be manageable
  - Solid wastes are expected to be biodegradable and usable as fuel (e.g. Cell mass)
  - Water will contain suspended solids and toxicity is not a serious concern
  - Water use for processing (especially for fermentation) may be a concern in arid or semi-arid regions
- Production As costs for bioproducts appear to be approaching those of conventional products, the cost of implementation of bioproducts could eventually be quite low
- Bioproducts will primarily off-set products now produced from partially imported petroleum, thus the cost of bioproducts, will be off-set partially by increased economic activity and tax revenues
- Most of the economic value-added in the production of bioproducts is added in the conversion plant, which is most likely located near existing chemical plants

We identified five key categories of barriers that impact all categories of options.

	Fundamental Technology Barrier	Cost not Acceptable	Address Early Adopter Markets	Poorly educated consumer	Regulatory Barriers
Biopower	• Gas cleaning for BIGCC must be improved • Design & eng. guidelines for co-firing implementation don't exist	• Cost of stand alone biopower is too high	• Black liquor gasifiers face market conservatism	• Biopower not seen as really green • RDF / Waste-to-energy seen as an "incinerator"	• Fly-ash regs for co-firing are restricting • Deregulation uncertainty • Biomass feedstock markets not well developed • New Source Review
Biofuels	• Organisms for CBP (consolidated bioprocessing) ethanol not robust • Gas cleaning for Bio-FT not adequate	• Cost of all options more than 1-2 times as expensive for fuel value of products	• Oxygenate markets prove difficult to substitute ethanol (market, infrastructure issues)	• Value of green fuels not recognized	• Ethanol credit only extend to all renewable fuels? • Limitations on GMO R&D and production
Bioproducts	• Fermentation-based commodity-scale production not well developed • Large-scale reactor technology not developed	• Cost of current technologies may still be too high for early adopter applications	• Need early markets for fermentation-based feeds	• U.S. consumer not very responsive to green branding • Competition with "biodegradable" fossil derived products	• Product standards for new chemicals not yet established • Limitations on GMO (genetically modified organism) R&D and production
Biomass Feedstock	• Recalcitrance of cellulosic biomass for applications other than power	• Biomass low energy density makes transportation costs key issue • Harvesting, yield	• Pulp & paper expand power production • Ag residues for more revenue for farmer	• Biomass equated with MSW; "garbage" • Biomass utilization plants perceived as "dirty"	• Markets for biomass not well developed • Competition among biomass forms (ag wastes vs energy crops)

Mapping the potential policy options against key barriers and considering their cost-effectiveness can help compare policy options.

Option Category	Absolute Cost	Typical Cost-Effectiveness	Effectiveness in Addressing Key Barriers				
			Fundamental Technology Barrier	Cost not Acceptable	Address Early Adopters	Poorly educated consumer	Regulatory Barriers
R&D Support	$	+++	+++	+	-	-	+
Direct subsidies	$$$$$	---	-	+++	+	-	-
Risk Sharing	$$$	++	+	++	++	-	-
Demonstration Projects	$$	+	-	-	++	-	-
Benchmarking / Best Practice	$	++	-	+	-	-	-
Voluntary Agreements	$$	++	+++	+	+++	+	+++
Standards / (de-) regulation	$	+++	+	+	++	-	+++
Infrastructure Investments	$$ / $$$$	+/-	-	+	+	-	-
Tax Measures	$$$	++	++	+++	++	-	-
Information Provision	$	+++	-	-	+	+++	-

Breakthrough Energy Technologies for Industry, Phase II Report, for Nederlandse Organizatie Voor Energie en Milieu. Arthur D. Little 1997

A selected set of policy options appear to be critical to achieving success in implementing increases in biomass use.

- R&D support is critical to achieve the necessary and sustained breakthrough improvements in technology performance and cost
- Voluntary agreements and public/private partnerships are critical to marshalling the level of resources necessary for large-scale implementation efficiently
- Tax measures can be used to entice early adopters and or bridge the cost-competitiveness gap for selected biomass options
- Information programs and consumer education programs are critical to internalizing the benefits of biobased energy and products in terms of product premiums
- Direct subsidies, price controls, or equivalent control measures (E.g. Renewable content standards) are likely the only way to have a chance at achieving the tripling goal can be achieved by 2020 in all sectors
- Sustained support, while not desirable from a global, free market perspective, may in fact be sensible on a national or regional basis

Overall, the opportunities for biomass-derived energy and products are considerable with environmental benefits and increased rural economic activity...

- In the near term, and with modest additional cost, considerable impact can be achieved by focusing on a number of practical options
- In the longer term, significant impact can be achieved with the further development of some higher-risk technologies
  - This impact takes the form of reductions in greenhouse gases and other pollutants
  - Increased domestic production of natural resources consumed in the U.S.
  - Increased high-value economic activity in rural areas
- Achieving a doubling or tripling of use of biomass energy and products is technically possible by 2015 or 2020
  - The development of new production and conversion technologies and the application to new markets could lead to this impact overall, and in each of the biomass use categories (power, fuel, and products)
- However, we recommend that the U.S. government carefully weigh the rate of increase in the use of biomass-derived energy and products against the cost
  - We believe that attempting to achieve rapid doubling of biomass energy and products use at all cost (e.g. by 2015) will lead to the application of technologies that could be superseded by superior and more cost-effective technologies only few years later
- Thus, we believe that a somewhat more long-term view of the biomass opportunity which allows for the development of technologies that could become commercial in the 2010-2020 timeframe, would be beneficial, and may lead to a more optimal use of resources for the benefit of the nation

...but the cost is very high so careful consideration of the desired rate is necessary.